From Sea to Source Protection and restoration of 2.0

restoration of fish migration in rivers worldwide



Sockeye salmon in Iliamna Laka, Alaska. © Jason Ching.

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Text and coordination

Kerry Brink¹ Peter Gough² Joshua Royte³ Peter Paul Schollema⁴ Herman Wanningen¹

Edited by

Chief Editor: Peter Gough² Text editor: Joshua Royte³

Chapter: Monitoring and Evaluation - Olle Calles⁵ Chapter: Dam Removal - Laura Wildman⁶

Project management

Herman Wanningen¹

- 1 World Fish Migration Foundation, The Netherlands
- 2 World Fish Migration Foundation, United Kingdom
- 3 The Nature Conservancy, USA
- 4 Regional Water Authority Hunze en Aa's, Veendam, The Netherlands
- 5 Karlstad University, Sweden
- 6 Princeton Hydro, USA

Photography

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Photography coordination

Wilco de Bruijne, OAK consultants, The Netherlands

Text control

Wendy Dolstra, The Netherlands

Drawings

Jeroen Helmer, Stichting ARK Natuurontwikkeling, The Netherlands (www.ark.eu)

Cartoons

Seppo Leinonen, Finland www.seppo.net

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Layout and cover design

Shapeshifter Visual Design www.shapeshifter.nl

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In the rainy season the Zambezi River floodplains provide habitat for more than 30 fish species, among which African tigerfish. Zambezi river, Barotse floodplain. © Annemarie Winkelhagen, WWF-NL.

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PREFACE

CAROLA SCHOUTEN

Minister of Agriculture, Nature and Food Quality, The Netherlands



"What kind of world do we want to leave to those who come after us, to children who are now growing up?". Pope Francis asked this in 2015, in his encyclical on the environment. It's a question that comes to mind now, as we discuss the issue of fish migration. Healthy fish stocks are important to us all. They are a crucial part of the food chain and also show us the state of the oceans. It is our common responsibility to keep fish stocks healthy, for the environment and future generations. If we can build a world where mankind and migratory fish can both thrive, I believe we are on the right track.

Protecting fish migration highways is something authorities cannot do on their own. Many migratory routes cross national borders and pass through regional waters, like the rivers Rhine, Meuse, Scheldt and Ems. So we need to work together to reconnect fragmented river ecosystems, in European policies like the Habitats Directive (Natura 2000) and the Eel Directive.

I am proud that Dutch hydraulic engineers are developing new concepts like 'building with nature'. In recent decades, natural processes have been the starting point for the design and implementation of waterworks. Dutch Water Authorities have invested heavily to improve connectivity for migratory fish. This has led to outstanding innovative projects like the Fish Migration River, which will allow fish to pass between the IJsselmeer and the Wadden Sea through the Afsluitdijk, yet also safeguards freshwater supplies. We are eager to share these positive trends with our colleagues around the world, which is why I am pleased by the contributions of Dutch experts in this book. Let's make every effort to ensure that underwater species are preserved for the wellbeing of the environment and of future generations. Let's connect!

GEERT-JAN TEN BRINK

President of the Regional Water Authority Hunze en Aa's, The Netherlands



As a regional water authority, we attach much value to clean and healthy waters in our management area. A healthy ecology must include fish populations of good quality and composition, however, this is not currently the case everywhere. This is often because of the presence of bottlenecks that constrain the free migration of fish. To address this we are constantly busy together with other interested parties, including our provinces, nature trustees, regional water authorities and the Angling Federation of Groningen and Drenthe in seeking solutions. I am proud of what we, as the regional water authority, have achieved with our regional partners since 2000. Of the 130 bottleneck points identified, 100 have now been provided with fish migration facilities. I am convinced that we have only been able to achieve this success through collaboration. Collaboration is not only applicable at regional and national level, but also internationally, after all, fish do not follow country borders! Through the creation and monitoring of fish migration facilities, much knowledge and skill has been built up and we would like to share this internationally in the new "From Sea to Source 2.0" project. A renewed step towards barrier-free fish mobility and the recognition of the importance thereof for ecology and environment is truly important if we are to achieve our targets for the environment.

JEREMY WADE

Host of River Monsters and former biology teacher, United Kingdom



Over just the last few human generations, big fish have become increasingly hard to find. As water-dependent creatures ourselves, we should all be concerned about this because most of these fish are apex predators, and as such they are indicators of the overall health of our rivers. Normally it's assumed that this decline is a simple result of over-fishing, but a closer look reveals a more complex picture. Many fish, we now know, make epic underwater journeys, to reach feeding grounds and breeding grounds, or they used to, until we prevented them from doing so, through our engineering of their environment. Originally, our disruption of their lives was through ignorance, but we no longer have that excuse. For the sake of our fish, and our rivers, and ultimately ourselves, it's time to help the fish swim free.

ZEB HOGAN

Host of Monster Fish, National Geographic Wild, USA



From Sea to Source is a practical guidebook with a simple premise - that healthy connected rivers are fundamental to human existence. Designed to share the challenges and successes of experts working around the world, it combines local perspectives for global impact. From Sea to Source is part of an urgently needed movement to develop a global network of informed scientists and citizens. It is a first step to a deeper understanding of the important connection between water, people, and aquatic life that is borne from our shared experiences. From Sea to Source can help turn the tide against unsustainable practices and toward a common goal: living rivers full of fish.

JACKIE KING

Institute for Water Studies, University of the Western Cape, South Africa



More than 3,000 hydropower dams are planned or being built on rivers. Multiple dams are planned for the world's great river basins, including the Amazon, Zambezi, Mekong, Salween, Indus, Yangtze, Okavango and Brahmaputra. This scale of development is threatening the diversity and resilience of whole river systems, altering or stopping the flow of water, sediments and biota, crossing national boundaries, affecting politics, causing human conflict, and leading to hydropower no longer being seen as 'green energy'.

Most of the dams are in developing countries where rivers great and small provide water, food and lifestyle support to hundreds of millions of people. I would like to see much better basinwide planning before dams are built or even contemplated, with a major focus on how river systems and their dependent social structures would be affected. I commend this book for helping to create awareness of what can be lost as well as gained as dams are built and what can be done to reverse the losses - but remember that it costs much more to fix than to care for in the first place and some things will not be fixable they will have disappeared forever.

ARJAN BERKHUYSEN

Director World Fish Migration Foundation, The Netherlands

Our organisation was launched because we felt that the many people working on great projects deserved more support. All over the world we see people working with passion and commitment to save and bring back migratory fish. Some are doing so because they love rivers, while others love to fish and others just like to be surprised by the wonders of living nature underwater. Many of them have managed to set up inspiring projects, such as dam removals and construction of innovative fish ladders. Many others are on the verge of doing so. I think they show that a future in which man lives in harmony with nature is possible.

By connecting these people, we believe we give their work and aspirations a boost, from local scales to global initiatives. Migratory fish connect us to the rivers and seas! We want to give migratory fish the freedom to migrate to fulfil their life cycle, for the benefit of all. That's why we promote the concept of free-flowing rivers. We must remove old and obsolete dams and weirs, build the best available fish passage solutions and ensure 'wise' hydropower planning.

Every two years we celebrate the World Fish Migration Day and the achievements of committed people who have opened more and more rivers. We believe that by working together we can make the difference.



SWIMWAYS OF THE WORLD

This poster was made especially for World Fish Migration Day.

It highlights iconic migratory fish species, their importance and the challenges around the globe. The full version of this poster can be downloaded in different languages at www.swimway.org

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EXECUTIVE SUMMARY

In 2012 our team proudly published the first global edition of our book "From Sea to Source". This was a work intended to inform, educate and inspire those who wanted to know much more about how to meet the challenges that lie behind restoration of fish migration in rivers around the world. Whether the challenge is simply to increase access to spawning habitats through connectivity improvements for salmon, or to maintain the livelihoods for hundreds of millions of people dependent upon fish and fisheries in the great rivers of Asia, Africa and South America, we hoped our book would help to achieve these goals.

That book was very well received and we were delighted with the good reviews. This inspired us to move on. An important result was the establishment of the World Fish Migration Foundation in 2014 through which we now continue to share experiences and encourage the opening of rivers around the world for wildlife and the people who depend on them.

Since the development of the World Fish Migration Foundation, many initiatives have been launched that promote a new vision: Connecting Fish, Rivers and People. The International Fish Passage Conference was held in The Netherlands in 2015, and World Fish Migration Day has been launched even more successfully around the globe. Together with our partners and collaborators we introduced millions of people from around the world to the urgent need for recognition of the value of migratory fish and healthy rivers. Flourishing populations of migratory fish are a wonderful indicator of environmental quality. Ultimately our ambition is to contribute in a positive way to making a better world and a positive difference for migratory fish, nature and humans on local and global levels by inspiring new initiatives for and with people all around the world.

With the release of the 2018 'From Sea to Source 2.0' we show how rivers are a critical natural resource that sustain us all and support livelihoods, health and wellbeing. Approximately 40% of all

fish species in the world reside in freshwater ecosystems, contributing economic and ecological benefits and value. Not only are there at least a quarter of a billion people who depend on freshwater fish as their primary food source, but the related fishing industry is a vital economic resource, worth \$90 billion annually in the USA alone. There is also a cultural aspect to fish populations and fisheries which has often been overlooked. People in many regions are rightly proud of their fishery traditions and they have a clear stake in restoring and protecting fish and their natural habitats.

Apart from the 15.000 freshwater fish species known to migrate in some way during their life cycle, there are over 1,100 iconic long-distance migratory fish that depend on free-flowing rivers to thrive. Among these are the great salmon runs of Alaska, the critically endangered sturgeon of Asia, the predatory tigerfish of Africa, the largest freshwater catfish of the Mekong, the highly migratory dorado in the Amazon and the wonderful ayu of Japan. Working together with international fish experts we have included details in this book on some of these key iconic migratory fish species and other less well-known fish from around the world in the hopes that this can be used to draw much-needed attention to these species and the pressures they face.

It is crucial that migratory fish can fulfil their entire lifecycle without the danger, delays and disturbance caused by migration barriers. For most species a barrier-free river system is sufficient, but many other salmonids, eels and lampreys also need free migration out into estuaries and oceans to fulfil their entire lifecycle.

As you will see, the threats to these habitats are well documented. At least half of all the flow in the rivers of the world is artificially manipulated or fragmented, and our resource of truly wild free-flowing rivers is now more threatened than ever. Only 64 of the 177 rivers, longer than 1,000 km, are free-flowing and yet there are proposals for more than 3,500 new large dams in Asia, Africa and South America.

In recent decades the upward trend of fragmentation, industrialisation, overfishing, climate change, water quality deterioration, and other threats have motivated people around the world to seek to improve the situation for migratory fish. River managers. NGO's. practitioners. researchers. authorities and other key groups are deeply concerned and starting to take action to address what is estimated to be a 40% decline in global migratory fish populations, part of an on-going negative trend seen over the last 40 years. An international fish migration community is growing, and has recognised the potential for a new era of opportunity to address pressures on migratory fish around the world. By reading this book, you should probably join this community too! We have learned to recognize the greater value of migrating fish and free-flowing rivers. and now investment to safeguard fish migration is becoming a growth sector. We are starting to see the first positive trends in fish populations in some parts of the world where action has been taken.

In this book we explain some of the inspiring work around the globe that people are doing to improve the status of migratory fish. This ranges from small local awareness campaigns by enthusiastic communities, to large multi-million euro restoration projects. A wide range of work to improve fish migration is presented:

- Increasingly, river managers and NGO's are recognising that many disused obstacles dams, weirs and culverts - can be removed to open rivers. We have seen the dam removal initiative grow by leaps and bounds in the USA where more than 1,400 dams have been removed. And now, with the launch of 'Dam Removal Europe', the movement gains pace and spreads. Across many European countries it is estimated that there are thousands of potential dam removal projects that will restore substantial portions of rivers;
- More and more fishways are being installed to help fish pass barriers that can't be removed.

One of the largest fish migration projects ever - the Fish Migration River project on the lower Rhine has been approved in Europe at a cost of 50 million euros. A big solution for a big problem, with the goal of restoring the great and crucial Rhine Swimway routes;

- There is increasing recognition of both the opportunity, but also the need to monitor the performance of fishways. In this way their performance can be demonstrated to all, but it is also important to learn lessons to improve future projects. Monitoring at restoration sites is showing that the eturning runs of sea-run fish, especially the river herring, are growing much faster and by much larger amounts than expected. Rivers can be restored more quickly than many ecosystems when constraints are lifted;
- There is an on-going revolution in managing fish migration at the river basin scale. The scope has become increasingly inclusive: incorporating entire migration routes within management plans and policies, multiple barriers assessed together, and collaborating with diverse partners to develop improved measures and monitoring, together with local communities and stakeholders. Cooperation has resulted in hundreds of kilometres of local river habitat restoration;
- International experts are increasingly sharing their knowledge and the challenges faced, and helping each other through expert meetings and webinars. The brainstorming of new and innovative ideas for the sustainable management of river systems, for example the 'Hydro-by-Design' approaches, can be very effective and achieve wonderful results;
- Engaging and communicating with society about migratory fish improves overall perceptions. Influencing policy is a key objective in many projects. Citizen science projects, visitor centres, and communication campaigns that shine a light on special fish have become more common and effective strategies to engage and inspire;

 There are many examples of effective mechanisms used to engage, educate and activate citizens and stakeholders. On a global scale, thousands of organisations celebrate World Fish Migration Day every other year to create awareness and attract public attention. In 2016 over 70 million people were engaged in World Fish Migration Day.

Inspiring stories are presented in this book along with hard lessons learned and great successes from nearly every continent. We present new case studies about people and their projects to restore our iconic fish species and the free-flowing rivers that support them. Examples are presented of the wide range of initiatives underway around the world, and information given that will be helpful to both beginners and experts alike. In this way we hope that students, practitioners, scientists, decision makers, and politicians can all make use of this book.

We have worked with many fish migration experts who have generously given their time, thoughts and experience so that we may share these with our audience around the world. Through our contributors we are able to present information and examples from around the world and we thank all of them for their invaluable support! They may each be contacted through their addresses presented at the back of the book. We would like to offer special thanks to our good colleagues and friends, Laura Wildman and Olle Calles who have made significant contributions throughout. We hope that more and more people, organisations and governments around the world are inspired by this work. Our ambition is to bring the global vision of 'connecting fish, rivers and people' to a growing audience and to encourage the 'Change Makers' of our world. These change makers are people who are enthusiastic and driven to pursue efforts to conserve and protect migratory fish. By working together we can develop much-needed global policy, technology, and appreciation needed to protect and restore fish migration routes.

Most sincerely, the authors,

Peter Gough Kerry Brink Joshua Royte Peter Paul Schollema Herman Wanningen

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CHAPTER 1 INTRODUCTION

Free-flowing river in the Altai-Sayan Ecoregion stretching across Russia, Mongolia, Kazakhstan & China. © Gernant Magnin.

Not Line

INTRO

This is the second edition of a global reference book on the protection and restoration of migratory fish worldwide. It is a follow up to the first global "From Sea to Source Guidance" (published in 2012), which was written in order to inspire decision makers and others working to reverse the global trend of declining migratory fish stocks around the world. Encouraged by the success of the first edition and expanding recent developments in the field, the World Fish Migration Foundation and their partners decided to update the version of 6 years ago with new and relevant information from around the world. Together with the valued support of our sponsors and input from numerous fish migration experts from around the world, this book is written with the ambition to continue to promote the field of fish migration on a global level in order to ensure that migratory fish stocks are protected and restored for future generations.



1.1 WHY FRESHWATER MIGRATORY FISH?

We currently know of about 15,000 freshwater fish species globally. It is likely that all such species migrate to some extent, between breeding and feeding areas, in order to complete their life cycles and to avoid seasonally unfavourable conditions. Some of these may be very short, whilst others cover extreme ranges sometimes in excess of 1.000 km. There are estimates of over 1.100 iconic long-distance migratory fish around the world. While there has been much global attention given to fish biodiversity and river conservation, only in recent decades has fish migration become a topic of significance around the world. This is because free migration is of fundamental importance to fish survival and it is threatened throughout the world.

Migratory fish have been vital to the wellbeing of human populations around the world for thousands of years, as they are a critical food resource. They are also essential components of the ecosystem and, because they move between regions, they are a potent indicator of the nature and health of our environment. They also represent a major commercial and recreational resource. In the USA, for example, a staggering \$30,4 billion is generated by the recreational fisheries sector out of a \$90 billion estimated total contribution (Rubin, 2015). Recent figures from England indicate a total annual figure of £1 billion generated by the inland fisheries sector (Peirson, pers. comm.).

Unfortunately, in this new Anthropocene age of human impact, most fish species are becoming more threatened by human activities such as the building of dams, weirs and locks, water extraction, river embankments, water quality issues, flow modifications from hydropower dams and, more recently, climate change issues (Gough, et al., 2012). As a consequence, many iconic migrating fish species including salmon, sturgeon and eel have increasingly become unable to reach their spawning grounds. Additionally the migrations of many other fish have also been disrupted causing 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, 2017).

Migration of sockeye salmon heading for spawning grounds Iliamna Lake, Alaska. © Jason Ching.



The issues causing migratory fish declines have led to extensive research and knowledge development, particularly for the large bodied, predatory species or those that have spectacular spawning runs in developed countries. In this book, we give a more global overview of migratory fish and relevant issues they endure. It is also shown how thousands of people around the world are working to improve the current status of migratory fish to restore and protect their populations for the benefit of all future generations.

1.2 THE CHALLENGE OF COMMUNICATION

The challenge to restoring 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.

Working with volunteers

Restoring spawning gravels and habitats for trout in the Longinoja brook at Helsinki, Finland. The project started 20 years ago and it is a successful trout-recovery project working with volunteers. © Henrik Kettunen.



Consequently the resolution of fish migration problems may not be achieved to the extent that we now know is necessary.

1.3 GLOBAL VISION

Thousands of people around the world are all working toward a common vision of **freeflowing rivers full of fish for the benefit of all!** Indeed, for many years, researchers, managers, governments, but also our increasingly motivated public, have been working to improve the situation for migratory fish by developing fishways, removing dams, rehabilitating rivers and exploring other solutions. In hundreds of publications and reports, experts have not only been highlighting data gaps and improved knowledge requirements, but also how important communication and collaboration is among various sectors.

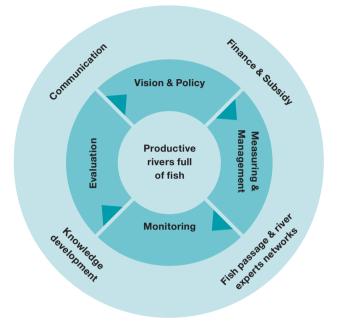
To facilitate communication, and provide a global platform for others to work towards a common vision, the "Swimway" approach has been developed by the World Fish Migration Foundation and their partners. The Swimway is an overarching framework, initially inspired by Birdlife's Flyway programmes, which works on the ground to save threatened migratory species and to integrate this with research, conservation, policy work as well as network development and collaborations across flyways (BirldLife, 2017).

The Swimway approach (Figure 1.1) is to promote understanding and recognition of migratory problems in the areas that fish species use to fulfil their lifecycle. The area needed may vary for different species; e.g. a European eel will travel for thousands of kilometres whilst the small three spined stickleback migrates over short distances between freshwater areas close to the coast and estuaries. **We call these areas "Swimway routes".** For many species the Swimway routes are limited to the freshwater section, estuary and coastal zone of river systems.

From a management perspective River Basin Approach plays an important role in restoring habitat and fish migration measures. This ter-

Figure 1.1

Schematic overview of the Swimway approach.



minology is also well-known in the world of river management organisations. It is an important reason why we still use the River Basin Approach as an important section of this book.

Using the Swimway approach is a great way to promote projects and activities that connect people, exchange knowledge, create awareness and develop close collaborations that will ultimately lead to open, free-flowing rivers for migratory fish. This approach is intended to bring people and projects together on a regional level and provide the opportunity to have an impact on policies from local to global.

1.4 GOALS OF THIS BOOK

As was the case in the first edition of the "From Sea to Source - International Guidance", this book 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 this book policy makers, water managers, ecologists and environmental engineers from all over the world should feel inspired to consider, address and reenergize prioritised fish migration measures from a river basin and swimway perspective. We cover a wide range of challenges and diverse solutions from around the world because we feel that we can always learn from other people's experiences. We are motivated by learning about the substantial energy devoted to resolving fish migration from nearly every continent of the world, and the success stories that are increasingly emerging.

Although the guidance is written to give an up-todate overview of fish migration topics worldwide, it cannot of course aspire to be comprehensive. Instead we highlight the growing importance of fish migration in environmental planning. In addition we draw on references to existing policy (and suggest perhaps the need for some new ones), while considering economic drivers, examples and restoration experiences from great projects accomplished around the world.

The main goal of this book is for us all to learn from examples of projects from countries around the world. Although precise circumstances clearly vary widely, 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.

1.5 HOW TO USE THIS BOOK

We use the Swimway approach as a practical way to integrate communication processes such as knowledge exchange, networking, collaboration, creating awareness, activating citizens, capacity building and education within the Swimway routes (Figure 1.1). This concept brings together and integrates all topics related to fish migration. In this book, each of these topics identified in the Swimway approach are detailed and illustrated with appropriate practical examples.

Fish migration specialists from all over the world have written about their challenges and successes. Through their examples they show how fish populations can be improved through the restoration of river connectivity. These examples also provide a platform to share information to a wider audience, beyond the practitioners and local stakeholders and communities. In each chapter a number of examples of projects and fish species descriptions are provided to demonstrate solutions for fish migration challenges from each continent! We hope the general and fish species examples we've selected in this edition highlight a diversity of problems and current solutions that can be easily shared and inspire more good work.

Figure 1.2

Visualisation of the Rhine Swimway Routes. In the Rhine there are 16 migratory fish species, including the European Atlantic sturgeon. This drawing was made to highlight these iconic fish species and their migratory routes, as part of the "Droomfonds Haringvliet" project. © Jeroen Helmer.



CHAPTER 2 THE IMPORTANCE OF RIVERS

Grizzly bear hunting for migrating sockeye salmon, Iliamna Lake, Alaska. © Jason Ching.

INTRO

Rivers are an integral part of functional landscapes. They play a critical role in providing pathways that allow the transport of energy, materials and organisms. They can act as filters and provide a diversity of habitats for a wide range of aquatic plants and organisms. Also providing critical resources for terrestrial organisms (Speed, *et al.*, 2016). They are dynamic and continuously changing and interacting along their length, width and through their depths. They are the lifeblood of the world and form a crucial resource for billions of people and economies. Understanding the importance of free-flowing rivers for both migratory fish as well as societal needs is essential to motivate thoughtful management of natural resources in and around rivers around the world.



2.1 FREE-FLOWING RIVERS

Rivers are among the most diverse and productive ecosystems on the planet. Although they only represent less than 1 percent of the earth's surface, nearly half of all fish species can be found in river ecosystems and millions of people depend on food produced within these ecosystems (Opperman, *et al.*, 2015). Natural and free-flowing rivers, in particular

offer considerable value. These are defined as any river that flows undisturbed from its source to its mouth without encountering any dams, weirs or physical barriers (WWF, 2006). Such free-flowing ecosystems are known to provide multiple social, economic and conservation benefits including provisioning services, regulatory services, and cultural and supporting services (Table 2.1). In addition to these services,

Provisional services	Regulatory services	Cultural & economic services	Supporting services
Providing ecosystems and human communities food and water	Free-flowing rivers play an important part in global water cycle	Recreational Value	Biodiversity: high con- nectivity rivers are among the most ecologically important habitats that are home to vulnerable spe- cies and high diversity of fish species
Providing much of the world's transportation	Water purification	Offering business opportunities including rafting, fly-fishing and wildlife watching	Balancing nutrients in soils
Provides freshwater necessary for drinking, hygiene	Flood mitigation: healthy floodplains reduce risk of floods and drought which are likely to increase with climate change	Spiritual and religious value for people	Carrying sediment downstream to nourish floodplains, deltas, and near-shore marine habitats
Fish and fishery products as an important food supply especially in developing countries: people depend on fish populations that require natural conditions to breed and thrive	Pollution control by transporting and removal of pollutants and excess nutrients		Providing range of habitats, flow and temperature regimes, and food webs that sustain iconic migratory fish and other species
Floodplain agriculture dependent on flowing river to bring nutrients, sediment and water	Sediment deposition in coastal wetlands and marshes protecting against storm surges and rising sea levels		Maintaining floodplains
			Habitat provisioning: connecting all functions and services with natural habitats provided by free- flowing rivers

Table 2.1 Key functions of free-flowing rivers (WWF, 2006)

EXAMPLE

Saving a rare, undammed major U.S. Atlantic River: The Delaware

Author: Organisation:

Country:

John Waldman Queens College, City University of New York United States of America



INTRODUCTION

At this time, few of the world's large rivers are substantially unmodified by humankind. The Delaware is no exception, but it does have one distinctive characteristic for a major watercourse in the Northeastern U.S., its main stem is not now and, has never been, dammed. Not coincidentally, its anadromous fishes are showing strong recoveries from other impairments.

The Delaware River begins with its East and West Branches in New York's Catskill Mountains, gathering in a single channel and winding between the borders of New York, Pennsylvania, and New Jersey, before feeding into its great estuary, situated between New Jersey and Delaware. Though still free-flowing, the river's main stem barely survived a highly contentious plan to dam it.

The Delaware once supported by far the largest population of Atlantic sturgeon in the USA, but it crashed in the 1890s because of overfishing impelled by an international caviar craze (Secor & Waldman, 1999). The river's populations of American shad and, especially striped bass, declined dramatically in the mid-1900s, largely due to industrial and sewage pollution in its lower reaches that was so profound (especially in warmer months when oxygen levels fell) that the river was said to have in effect, an impassable "chemical dam."

ACTIONS UNDERTAKEN

The "Tocks Island Dam" proposed in 1965 by the U.S. Army Corps of Engineers would have created a 37-mile long reservoir between New Jersey and Pennsylvania, thereby preventing several anadromous fishes from reaching their spawning grounds. Strong resistance helped defeat the project (Waldman, 2013). This included from activists who illegally occupied portions of the land in question and formed the Delaware Valley Conservation Association, and from a series of enlightened politicians who had ongoing environmental and financial concerns.

Long before Tocks Island Dam controversy, the river's Atlantic sturgeon fishery ended quickly following near total depletion of the stock circa 1900. However, severe water quality impairments continued unabated for decades at the head of the estuary near Trenton, New Jersey, which affected all of the river's migratory fishes. It was not until 1972, with the passage of the federal Clean Water Act that the Delaware River and many other urbanized watersheds began their recoveries from gross levels of pollution (Weisberg *et al.*, 1996). **DELAWARE RIVER AT PHILADELPHIA, 1928** © Municipal Archives of Philadelphia.



OUTCOMES

Today, after some 100 years of uncertainty as to whether even a relict stock persisted, the Delaware's Atlantic sturgeon is demonstrating a strong recovery (Wirgin *et al.*, 2007). Additionally, the Delaware's population of the federally endangered shortnose sturgeon

RESEACH IN THE DELAWARE RIVER Pulling in seine net at Lambertville Shad Festival. © Hunterdon County Democrat.



remains robust. The striped bass population of the river has shown steady growth since the 1980s and is now contributing to coastal fisheries (Waldman & Wirgin, 1994). The Delaware's American shad population currently is among the healthiest on the East Coast. And sea lamprey continue to favor this watershed.

LESSONS LEARNED

The anadromous fish of the Delaware River benefited from one action not taken and another taken. To flourish, migratory fish require both unfettered access to their spawning grounds and adequate water quality. Along the American Eastern Seaboard most rivers have only one of these-adequate water quality-but their migratory fish populations remain hindered in their movements by one or more dams.

Avoidance of construction of a mainstem dam on the Delaware together with the river's return to cleaner waters was a forceful combination in unleashing the river's native ecology, including a recent renaissance of its migratory fishes.

EXAMPLE

Sambor Dam and the Sekong-Mekong-Tonle Sap Corridor

Authors: Organisation:

Country:

Zeb Hogan & Teresa Campbell Global Water Center, University of Nevada, Reno Cambodia



THE KHONE FALLS IN THE MEKONG RIVER © Zeb Hogan.



INTRODUCTION

The Mekong Basin in Southeast Asia has nearly 900 recorded species of fish (Ziv *et al.*, 2012), many with complex migrations between diverse habitats (Baird and Flaherty, 2004). Hydropower development over the last decade has eliminated many migration routes for Mekong fishes (Stone, 2016). One of the last major undammed corridors between distinct and critical fish habitats is the Sekong-Mekong-Tonle Sap corridor through Cambodia, Lao PDR, and Vietnam.

The Sekong River, the last major undammed tributary of the Mekong, begins in the central highlands of Vietnam and ends in the Cambodian lowlands, flowing through diverse habitats that promote high fish diversity (Meynell, 2014). The Sekong has 213 recorded fish species, including 15 endemic and 64 migratory, 18 of which are believed to migrate from the Tonle Sap River to the Khone Falls in southern Lao PDR (Baran *et al.*, 2013). The mainstream Mekong River in Cambodia has deep pools that are important dry season refuge habitat and possibly spawning habitat for large, migratory fish (Poulsen *et al.*, 2002).

The Tonle Sap Basin is globally renowned for its biodiversity, boasting 328 recorded fish species (Ziv *et al.*, 2012), and sustains a critically important fishery for Cambodia. Its floodplains are essential spawning and rearing habitat for many migratory species (Campbell *et al.*, 2006). Available evidence suggests major migrations occur between Tonle Sap Lake, the Tonle Sap River, the Cambodian Mekong, and the Sekong River. The Sambor Dam planned for construction on the mainstem Mekong in Cambodia would sever connectivity between these critical habitats and lead to sedimentation of pools and alteration of the flood pulse, possibly eliminating whole populations of migratory fish and severely affecting non-migratory species (Lee and Scurrah, 2009).

ACTIONS UNDERTAKEN

In response to the increased hydropower threat to fisheries sustainability, numerous studies have been launched to better understand fish migrations and habitat requirements and inform decision makers of true ecological and economic costs of dams. Scientists, environmental agencies, and concerned stakeholders are pushing for revised power concepts and effective mitigation techniques for fish passage and flood control (Stone, 2016).

OUTCOMES

Although the Mekong River Commission recommended a 10-year moratorium on mainstem dams in 2010, and study results unanimously predict poor outcomes for migratory fish (which comprise 71% of Lower Mekong fisheries (Barlow *et al.*, 2008), two mainstem dams are now under construction in Lao PDR and 9 (including Sambor) are planned for Lao PDR and Cambodia (Barlow, 2016). Numerous tributary dams are planned, under construction, or completed (Ziv *et al.*, 2012). Mitigation measures are sometimes ignored or are unlikely to be effective for many migratory species (e.g. Baran *et al.*, 2011).

LESSONS LEARNED

The predicted detrimental impacts caused by dams to Lower Mekong nations' fisheries, food security, and economies have not been enough to deter building or ensure proper design and operation of dams. Improved international infrastructure to enact and enforce environmental protections is required. An approach to dam building that considers hydropower needs with environmental and social impacts is crucial to achieving improved siting, operations, and mitigation for dams like Sambor (Barlow, 2016).

A GIANT STINGRAY CAUGHT IN THE MEKONG RIVER, CAMBODIA (202 cm width 413 cm length) © Zeb Hogan.



Continent	Number of free-flowing rivers >1000 km	Longest free-flowing river (river basin)	Length (km)
Africa	8	Kasai (Congo)	2153
Asia	22	Lena	4410
Europe	5	Pechora (Northern Dvina)	1809
North America	6	Mackenzie	5472
South America	20	Amazon	6516

Table 2.2 Free-flowing rivers around the world (WWF, 2006)

migratory fish. Research has shown that freeflowing rivers provide a range of habitats, flow and temperature regimes, and food webs that sustain iconic migratory fish and other species. These all differ depending on the species and the nature of river systems around the world. This has presented problems in managing river systems, especially in regions where knowledge about the behavior of migratory fish and responses to changes in free-flowing river systems is largely unknown. In Africa there are hundreds of fish species that are considered migratory, but only a small percentage of studies have detailed quantitative data to support understanding of

free-flowing rivers are crucial for the survival of

their migratory habits and dependence on freeflowing river systems. As a result it is more challenging for managers to present adequate management and mitigation plans specific for the region and species.

Free-flowing rivers are also critical for supporting the livelihoods of rural populations in many developing areas. For instance in productive floodplains and deltas that are driven by freeflowing rivers, people are able to harvest millions of tons of fish (Opperman, *et al.*, 2015). It has been estimated that approximately 14-32 million tons of fish harvested from river-floodplain ecosystems provide enough food for around 225-550 million people on a fish-dominated diet. People also take advantage of the annual floods within the floodplains and deltas for floodrecession agriculture and the nutrients that are transported for maintaining wild capture harvests. Despite the natural benefits enjoyed by mankind over millennia, our growing population and associated industrialization has placed great demands on our rivers. Over the years the number of free-flowing rivers has become few and far between. There has been an inexorable rise in the development of impoundments to meet water, energy and transport needs and to control and regulate natural flows. According to Grill. et al. (2015), 48% of the total volume of rivers around the globe is moderately to severely impacted by artificial flow regulation and/or fragmentation. These impacts on free-flowing rivers severely affect the migratory patterns of fish and damaging their habitats. See Chapter 3 for more detailed insights into the effects.

In recent years World Wildlife Fund, McGill University, and partners have been developing a methodology using global datasets to identify such rivers around the world (Michele Thieme, 2018 pers. comms.). This will be published in 2018. In 2006 a preliminary review was conducted on 177 rivers longer than 1,000 km: only 64 (less than 40%) of those remained free-flowing and many were threatened by proposals for new dams.

Most of the remaining free-flowing rivers were actually tributaries of even larger rivers: 20% were tributaries of the Amazon, while another 20% were rivers of the far north and east of Russia (WWF, 2006). Only one long river in Europe (the Pechora, rising in the Ural Mountains and flowing to the Barents Sea) remained largely unmodified. The threats to these few remaining rivers has led to a call to governments to safeguard them. WWF reported that the remaining free-flowing rivers are ecologically essential, acting as bio-reserves for important natural and cultural resources, and provide key services for people. These rivers perhaps serve as a testament to humankind's restraint, and moral responsibility to future generations. We recommend that this position be urgently reviewed by global leaders if these great rivers are to be preserved for the future.

More detailed studies of smaller rivers show that free-flowing rivers are increasingly rare features in local landscapes around the world. In South Africa, only 62 free-flowing rivers have been identified, of which only 25 are longer than 100 km (Nel, *et al.*, 2011). In the USA, the Nationwide River Inventory (NRI) listed 3,400 free-flowing segments of rivers that are believed to possess one or more "outstandingly remarkable natural or cultural value" (National Parks Service, 2011).

2.2 RIVERS AROUND THE WORLD

Rivers around the world are incredibly diverse with a wide variety of natural features, differing greatly in size, geology, slope, base flow, climate, temperature, chemistry, discharge, floodplains, biological diversity (Tockner, *et al.*, 2009; Cushing, *et al.*, 2006; Welcomme, 1985).

In North America, much of the continent drains into the Mississippi. The largest river on the continent and the fourth largest in the world, with a length of 6,275 km and drainage area of 2,980,000 km². In South America, the rivers in the west drain from the Andes to the Pacific. They are short, steep and therefore torrential, while the rivers to the east have massive catchments that drain to the Amazon. This is the largest river in

GLOBAL ASSESSMENT OF FREE-FLOWING RIVERS

Michele Thieme, WWF (USA)

INTRODUCTION

Free-flowing rivers are the freshwater equivalent of wilderness areas; however, in many parts of the world, remaining free-flowing rivers are considered even rarer and more imperilled than terrestrial wildernesses and pressures on remaining free-flowing rivers threaten to accelerate the decline of freshwater species in many river systems. No global registry of free-flowing rivers exists to underpin monitoring of their status over time and to help catalyse protection of those of highest conservation value.

WHAT DID WE DO?

To address this gap, World Wildlife Fund (WWF) and McGill University are leading an updated global assessment to identify rivers that remain free-flowing and provide a baseline that will allow tracking of the connectivity status of rivers over time. The research team also includes representatives from Kings College London, Umea University, University of Washington, UNESCO-IHE, University of Nevada-Reno, University of Tubingen, University of Wisconsin, Leibniz Institute of Freshwater Ecology, The Nature Conservancy and Conservation International. After extensive deliberations, the team has defined free-flowing rivers as those in which:

Natural aquatic ecosystem functions and services are largely unaffected by changes to fluvial connectivity allowing an unobstructed exchange of material, species and energy within the river system and surrounding landscapes. Further specifying that the longitudinal (river channel),

EXAMPLE

Rivers of Kruger National Park in a sea of dams

C. O'Brien ¹ , Matthew Burnett ¹ &
etersen ²
ity of KwaZulu-Natal &
frican National Parks
rica



Within southern Africa, in the Limpopo and Inkomati River Basins of Mozambique and South Africa, a large diversity of sub-tropical fishes occur, which are remnants where the now Zambezi River flowed south into the region and out into the Indian Ocean (Skelton, 2001). Within this region, is the world renowned Kruger National Park (KNP) which forms the national boundary between South Africa and Mozambique. This almost two million-hectare nature reserve is famous for its megafauna and terrestrial conservation endeavours including the remaining stronghold of many red data species (Rogers and Biggs, 1999; Roux *et al.*, 2008).

The KNP has five major rivers flowing through it in an easterly direction. All of these rivers originate outside of the KNP in South Africa with only a few small tributaries occurring entirely within the KNP. Unfortunately, all of these rivers have been significantly altered by upstream land use activities including dam developments, which results in water quality stressors, altered flows, altered habitats and alien species and diseases stressors entering the KNP from upstream (Rogers and Biggs, 1999). In addition, all of these rivers have been dammed or are planned to be dammed in the near future resulting in the rivers within the KNP being referred to as "rivers within

SABIE RIVER FISH POPULATIONS

A) Monitoring the fish populations upstream from the Corumana Dam. © Herman Wanningen. B) African fish eagle with its catch. Rivers in the KNP forms the life veins of the reserve. A diversity of wildlife depend on these rivers and the resources they provide for their survival. © Herman Wanningen.





a sea of dams" (Nel *et al.*, 2007; Pers. Comm. Riddell, 2016).

Prior to anthropogenic developments in the region (<1930s), the KNP Rivers provided habitats for most of the fish diversity from the region including many catadromous, diadromous and potamodromous fishes (Pienaar. 1968). These migratory fishes made use of the rivers, estuaries and marine ecosystems downstream of the KNP and migrate into the KNP and often upstream of the KNP (>300 km). With the development of land and water resource use activities in the region. the KNP became a refugium for many aquatic animals (Rogers and Biggs, 1999). This also provided the surrounding areas with a source of biodiversity through migrations, contributing to the resilience of the region (Roux et al., 2008).

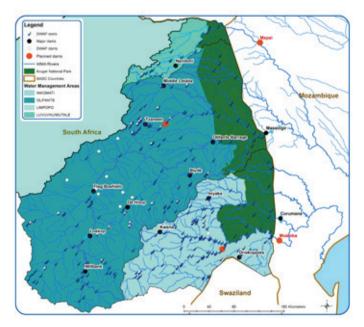
With the establishment of the Water Act of South

Africa in 1998 the regulations to attain a suitable balance between the use and protection of water resources were established. A limitation of this process includes omitting important, but partly unknown, ecosystem processes.

River connectivity and its associated processes is such a requirement that has largely been omitted from regional water resource management. An example is the rivers of the KNP where regional barrier formation has negatively affected biodiversity and ecosystem processes that have social and ecological consequences. The cost-benefit of retrofitting mitigation measures to physical barriers in the region is extremely low and threatens the economic viability of water use activities. Our unforeseen omission is destined to persist, and our important fishes of the KNP will remain out of sight and out of mind in these rivers amongst a sea of dams.

FIGURE 1

Inkomati, Olifants, Limpopo and Luvuvhu River Catchments in the Kruger National Park along with the major dams and weirs. © Robin Peterson.



lateral (floodplain), vertical (groundwater and atmosphere) and temporal components of fluvial connectivity can be compromised by (a) infrastructure or impoundments in the river channel, along riparian zones, or in adjacent floodplains; (b) by hydrological alterations of river flow due to water abstractions or regulation; and (c) by changes to water quality that lead to ecological barrier effects caused by pollution or alterations in water temperature.

Okna River, Morske Oko Reserve, Slovakia Wild Wonders of Europe, WWF. © Konrad Wothe.



HOW DID IT WORK OUT?

Best available global datasets have been compiled that correspond with pressure factors that affect different components of river connectivity and for which global data were available: (a) river fragmentation; (b) flow regulation; (c) water consumption; (d) road construction; and (e) urbanization. For each pressure factor, proxy indicators were constructed using global data and combined into one index of connectivity status. Each reach of river globally (8.5 million reaches and 12 million km of river) has been evaluated for its "free-flowing" status based on the level of disturbance to its connectivity components. A

river must maintain a high level of connectivity along all river reaches from source to outlet (outlet being defined as intersection with next largest river or the ocean) to be considered "free-flowing". The methods have been tested for robustness both at global scale and in several geographies (Tapajos Basin, Brazil; Uttarakhand State, India; Luangwa River, Zambia). The assessment methods and results are under scientific review and will be available publicly in the future. For more information, visit www.worldwildlife.org/pages/free-flowing-rivers.

Free-flowing Vatsna River, Iceland

Containing a natural stock of Atlantic salmon and sea trout. © Wilco de Bruijne.



the world with a catchment area of about 7 million km² and an average discharge greater than the next thirteen longest rivers combined.

In Europe, there are 164 major catchments, of which 150 are transboundary and cover 17 key geographical regions.

The rivers in Asia, including Russia, display great geographical diversity from the arid Tigris and Euphrates systems in Iran to the humid, tropical Mekong river flowing through narrow deep gorges to the Mekong delta and covering an area of 62,520km².

African rivers provide resources and services that are a fundamental part of the past, present and future lives and livelihoods (Sadoff, *et al.*, 2002). These rivers are also some of the most variable and volatile due to exceptional variability in precipitation, resulting in anything from major flooding to major droughts.

Australia is home to 12 catchment divisions, including the Murray-Darling catchment in the south-east of the country as well as the unique dry inland rivers flowing from the central regions.

2.3 ECOLOGY OF RIVERS

Rivers are highly complex environments due to the constantly changing interactions between physical features, weather, altitude and gradient, flow regimes, energy shifts, biological interactions and water quality. The integrity and productivity of free-flowing river systems depends largely on the continuity of hydrological processes and nutrient cycling, as described in the river continuum concept.

2.3.1 Hydrology

Rivers typically originate in upland areas from springs and wetlands that coalesce when there is enough volume to form an intermittent and/or perennial stream channel. As streams combine with other tributaries they form larger, more smoothly flowing and deeper rivers that commonly meander through lowlands towards the sea. Topography, geology, and climate are key factors that influence this. The discharge of rivers depends on the size of the catchment and the amount of rainfall that finds its way into streams. In mountainous areas or northern latitudes precipitation can fall as snow that may significantly supplement discharge during the spring thaw. Seasonal influences on discharge lead to characteristic patterns of flows in different

FASCINATING DIVERSITY OF RIVERS IN RUSSIA Dmitrii Pavlov, A.N. Severtsov Institute of Ecology & Evolution, Russian Federation (Russia)

There are 2.5 million rivers, brooks and temporary streams in Russia of which 57 are longer than 1,000 km. Only 17 of these rivers flow into either seas or large inland lakes, the others are tributaries of larger rivers. 90% of Russian rivers flow into the Arctic Ocean and the Pacific Ocean, and 7.5% of rivers flow into the Azov-Black Sea basin and the Caspian Sea basin.

Fourteen large rivers flow through the European part of Russia. The largest river of Europe is the Volga River, it has a total length of 3,531 km, a catchment area of 1,36 million km², and an average annual runoff of 228 km³ flowing into the Caspian Sea. Other large rivers of the Caspian Sea basin are the Ural, Kama, Oka, Belaya, Vyatka. Large rivers of the Azov-Black Sea basin are the Don, Khoper, Dnieper, Desna, northern Donets. Large rivers of the White Sea basin are the Northern Dvina, Vychegda. The largest river of the Barents Sea basin is the Pechora River and the largest river of the Baltic Sea basin is the Western Dvina River.

MAJOR RIVERS OF THE



- 1 Yukon
- 2 Mackenzie
- 3 Nelson

4 Columbia

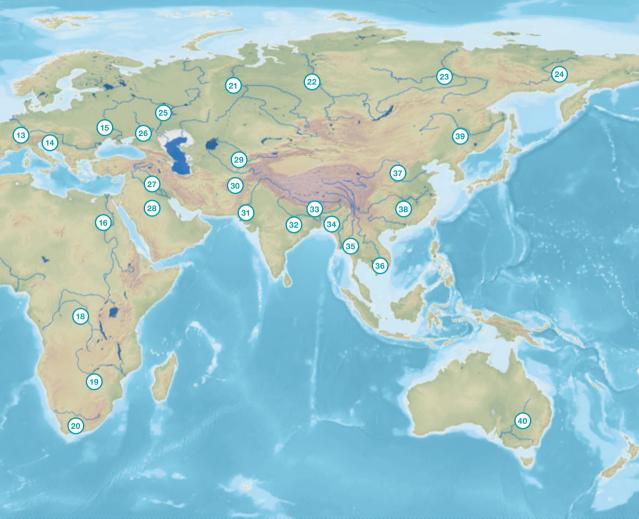
5 Colorado

- 6 Rio Grande
- 7 Mississippi

- (8) Orinoco
- 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

EXAMPLE

Unlocking the UK's longest river the forgotten history of *Alosa fallax* on the River Severn

Author: Organisation: Country: Mike Morris Severn Rivers Trust United Kingdom



INTRODUCTION

Geographic range

The twaite shad *Alosa fallax* is a migratory fish found in major rivers and in open waters along the coasts of the Atlantic (Ireland and Scotland to Morocco), southern Baltic, North and Mediterranean Seas. Its conservation status in the Atlantic bioregion is 'unfavourable-bad' and deteriorating; however, its status is not the same across the region with cases of improvement (Belgium and United Kingdom) and deterioration (France).

UK context

A. fallax, along with A. alosa, is one of only two members of the herring family in the United King-

DIGLIS WEIR

Diglis Weir: the first barrier for shad on the River Severn. © Unlocking the Severn.



dom. Spawning *A. fallax* is at its northern extent on the Severn Estuary Special Area of Conservation (SAC) in the UK (Aprahamian *et al.*, 2003). Since the Industrial Revolution in the mid-19th Century, the species has declined considerably in abundance throughout its geographic range (Aprahamian *et al.*, 2003). Its decline on the Severn has been attributed to navigation weirs constructed around 1842 (Day, 1890). The weirs at Worcester have prevented the *A. fallax* from reaching their historic spawning grounds, which extended as far as Welshpool (Salmon Fisheries Commission, 1861) and the River Vyrnwy (Pennant, 1810) in Wales.

THE SOLUTION

In 2013 a partnership came together to return the twaite shad to its natural spawning range by opening up the River Severn and its tributary the River Teme. In 2016, the Severn Rivers Trust, Canal & River Trust, Environment Agency and Natural England secured funding from the Heritage Lottery Fund and European Union's LIFE Nature Programme for a five-year Unlocking the Severn for LIFE project to improve fish passage across four weirs on the Severn and two on the Teme, and as importantly engage the local community to protect this largely forgotten species in the region. The partners will use best practice solutions developed from global learning including deep vertical slot passes and bespoke easements that will improve access for all fish species in the river, focussing on shad.

Surveys undertaken in 2014 show the habitat on both these rivers, and upstream of the impacts of the upper most barriers, is suitable for *A. fallax* spawning and nursery provision. By 2021, the project will increase the UK favourable reference length and therefore the favourable reference population within the Natura 2000 network by 253 km to 518 km, contributing 61% of the UK's *A. fallax* population.

FUTURE CONSIDERATIONS

At the time of writing, four tidal electricity generating lagoons are being considered throughout the Bristol Channel and the lower Severn Estuary SAC. This could have significant impacts on the free movement of all 110 fish species found in the area including both Alosa species and five other migratory species. Any proposals would have to meet EU Habitats Directive obligations and comply with regulatory frameworks but with the UK due to leave the European Union in 2019, the project partners will be working closely with the relevant UK governmental bodies to ensure ongoing protection.

FIGURE 1

Location of the Severn Estuary.

Legend





Many of the rivers longer than 1,000 km (43 rivers) flow through the Asian part of Russia. The longest rivers here are the Ob (5,410 km), Lena (4,400 km), Yenisei (4,102 km) rivers, which flow into the Arctic Ocean while the Amur River (4,440 km) flows into the Pacific Ocean. The Yenisei River has the highest river flows (624 km³/year), making it the fifth largest, by volume, in the world. At present most rivers are regulated in Russia, both in the European part of the country (the Volga, Don, Kuban Rivers, etc.) and in Siberia (the Ob, Angara, Yenisei, Amur, Kolyma Rivers, etc.). Whole series of hydropower projects have been built on many rivers or on their tributaries. These dams have interrupted the routes of spawning migrations of fishes. It has led to the loss of access to spawning grounds, thereby destroying millenia-old cycles of reproduction. Only one large river in Europe, the Pechora River, remains free-flowing.

In Russia, in 2009, water consumption was estimated at 62.5 km³/year (Danilov-Danilyan, 2009). There are some water intakes the consumption of which can be compared with water discharge of large rivers. For example, the Mariano-Cheburgolskaya irrigation system, which diverts water from the Kuban River and supports water consumption of more than 200 m³/s. During downstream migrations billions of juvenile fish are entrained by these abstracted water currents and enter into artificial canals where they die.

The regulation and water consumption on many inland water bodies has drastically changed the ecological conditions of aquatic organisms and led to a sharp decrease in abundance of commercial fish species (e.g. river basins of the Azov Sea and the Caspian Sea). Some indigenous fish species were listed in the Red Data Book of the Russian Federation (2001). To protect migratory fish species various structures facilitating fish passage (fish locks and fish lifts) are used. In order to improve the fish habitats, different conservation activities are performed and to increase fish abundance, the natural stocks are supplemented with hatchery stocks.

In these basins, there are large amounts of anadromous juveniles added for the restoration of migrating fish species such as sturgeon (*Acipenser gueldenstaedtii*), stellate sturgeon (*Acipenser stellatus*), beluga (*Huso huso*), whitefish (*Stenodus leucichthys*), Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), etc.

Gore River delta

Located in the Komsomolsky Zapovednik Nature Reserve. Amur floodplain, Russian Federation. © Hartmut Jungius, WWF.



Sand bars in the Lena River Sakha Republic (Yakutia), Russian Federation. © Hartmut Jungius, WWF.



parts of the river system. Some rivers show great fluctuations in flow while others, some fed by groundwater, have an almost constant flow throughout the year. Some streams show seasonally predictable flows, while others have irregular flow patterns. In free-flowing rivers these fluctuations and flood pulses define the river ecosystem along with the biological productivity, biodiversity and ecological succession (Poff, *et al.*, 1997).

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 months or years and consequently the fish fauna is limited and dominated by species that are adapted to protective migration strategies, and seasonal colonisation. Dry river channels usually have relatively unvegetated banks due to the limited opportunity for establishment of riparian plants which has implications for input into streams. shade, and stream channel stability. In contrast, large and permanent rivers often support a high riparian and aquatic species diversity. As a consequence of seasonal pulses of rainfall or snow melt many rivers develop lateral floodplains formed outside the normal riverbed. These floodplains are characterised by a high degree of lateral movement of water and sediment. They have corresponding zones of vegetation and stream channels which many organisms are adapted to and depend on. Fish often use seasonal or temporarily inundated areas for foraging, spawning and nursery areas. Free movement between these river and floodplain habitats (lateral migration) is often an important feature of such habitats and leads to a greater diversity of species and often larger more productive fish and other wildlife. Floodplains differ substantially in size, and today the extent of many has been profoundly influenced by management, such as development of roads, dikes and levees for flood management, and dams controlling flood periodicity. For example, the largest natural floodplains in Europe were in the River Danube catchment, however only fragments of these now remain due to human activities over the last more than 1,000 years.

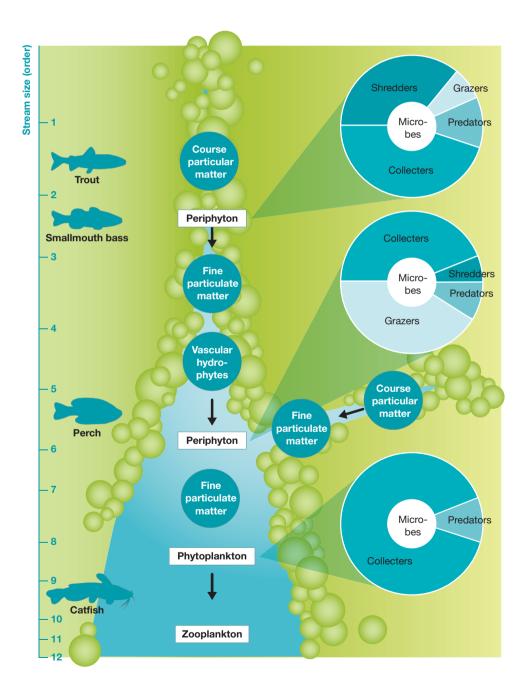
2.3.2 Nutrient cycling

In free-flowing rivers, nutrients in often shady headwater sections of the river are largely dependent on allochthones (external material falling into streams) energy resources, hydrology and nutrients. As rivers meander downstream toward their floodplains, nutrients are transferred in a trophic spiral, with input from more tributaries, more sunlight reaching more of the stream producers, there is more and more life that supports a larger and more complex food web. As such, larger rivers systems lower in their basins require fewer external nutrients and tend to produce more internal organic material than it consumes. These processes are highly dependent on having connectivity and the continuous transport of material down the river channel from the source to the deltas. This growing complexity can be translated into functional feeding groups of organisms as shown in Figure 2.1.

From a geochemical point of view, migrating fish can be key in the transport of nutrients within free-flowing riverine systems (Friedl & Wuest, 2002). Migratory fish transport nutrients with their bodies from the ocean into the rivers, for example it has been shown that Pacific salmon (Onchorhynchus spp.) transport marine-derived nitrogen (in their faeces, spawning, and dying adults and iuveniles) to rivers where they spawn. and that riparian growth rates are significantly enhanced by those nutrient inputs (Helfield & Naiman, 2001). Ecological studies have 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 (Hocking & Revnolds, 2011). Most 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. Studies show how Pacific salmon transport marine-derived nitrogen to

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).



rivers where they spawn and that riparian growth rates are significantly enhanced by the nutrient input from the decomposing adults. This nutrient loading shifts the plant communities toward nutrient-rich species. Helfield & Naiman (2001) hypothesised that the increased nutrients in the system also act as a positive feedback for the subsequent salmon generations. Predicting how salmon affect terrestrial ecosystems is central to conservation plans that aim to better integrate ecosystem values into resource management.

2.3.3 Biological zoning

Biological zoning is the characterisation of a water course into different biological zones,

typically based on fish species. The distribution of fish species in any river varies according to the physical properties such as flow, bottom substrate, temperature and depth of the watercourse. Some fish species are bound to particular river stretches where the characteristics suit particular stages of their life history. The names of these species have been used to label 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

Migrating pink salmon

While fulfilling their life cycle, migratory species such as salmon transfer nutrients from the ocean to inland ecosystems. The carcasses of adult salmon provide a significant nutrient source for wildlife such as bears and for the aquatic and riparian ecosystem as a whole. Migrating pink salmon, Great Bear Rainforest, British Columbia, Canada. © Steph Morgan, WWF-Canada.



SPECIES EXAMPLE

Ecology of the Goliath catfish *Brachyplatystoma rousseauxii* (Castelnau 1855)

Authors:	Rosa Maria Dias ¹ , Anielly Galego de Oliveira ¹ , Rafaela Giacomel Rauber ¹ ,
	Mirtha Amanda Angulo Valencia ¹ , Angelo Antonio Agostinho ¹ & Ronaldo
	Barthem ²
Organisations:	¹ Universidade Estadual de Maringá/NUPÉLIA/PEA & ² Museu Paraense Emílio
	Goeldi-Campus de
	Pesquisa-CCTE
Country:	Brazil

FIGURE 1

Distribution area of B. Rousseauxii. Different catchment locations used during the life-cycle: orange is the nursery area; blue is the feeding area (juvenile and adults); green is the spawning area. The star marks the Teotônio Rapids. Modified from the illustration drawn by Gabriel de Carvalho Deprá from website: https://revistabioika.org/pt/



BIOLOGY AND ECOLOGY

The "dourada" *Brachyplatystoma rousseauxii* performs the largest known potamodromous migrations for breeding and feeding (up to 5,786 km; Barthem*etal.*, 2017). It is widely distributed in the Amazon Basin including the Andean tributaries of Bolivia, Colombia, Equador and Peru. *B. rousseauxii* is known for its high economic importance, its exceptional lifecycle and its large size, reaching 192 cm in length (Barthem & Goulding 1997). It shows seasonal reproduction, high fecundity, external fertilization and absence of parental care. Dourada is a piscivorous sensorial predator, feeding mainly on fish living in the water surface.

LIFE-CYCLE

B. rousseauxii shows a complex life-cycle that is still non-entirely understood (Batista *et al.*, 2009). Juveniles are abundant in the Amazon estuary, in the eastern Amazon, while the mature fish only occurs in the western Amazon. The fishery catch consists of mature individuals caught close to the Andes and occasionally in the upper portion of the Branco River, in Roraima. Young fish spend around one or two years feeding on available resources in the estuary before they start their upriver migration. Fisheries data show the upstream movements of pre-adults and adults in shoals from the estuary towards the lower Amazon River and the Central Amazon (including Madeira) between August and October. Schools of the grown B. rousseauxii reach the Andes foothills to spawn throughout the year, but the high density of postspawning drift larvae indicates the rainy period in the Andes as the most important time for reproduction. Genetic studies of *B. rousseauxii* shows divergent results for population homogeny in the Amazon Basin, and there is a hypothesis of homing behavior (Batista & Alves-Gomes. 2006).

HUMAN IMPACTS

B. rousseauxii suffers from the same threats as other migratory species: overfishing, habitat destruction, pollution and dam construction, The growing number of hydroelectric dams in the Amazon basin blocks its migration routes, reduces the home range and prevents completion of the life cycle (Winemiller et al., 2016). (e.g. the Teotônio rapids, a place frequented by fisherman to capture the "dourada" during the upstream migration, are now under the Santo Antônio Dam on the Madeira River). The interruption of downstream migration of juveniles could affect recruitment success. The species is also threatened by expected development in the Andes, adding to dams, headwater deforestation and mining activity (Barthem et al., 2017).

POSSIBLE SOLUTIONS

Additional studies of the population structure of *B. rousseauxii* are urgent to confirm whether there is homing behavior. Conservation must take account of the risk of loss of genetic variability. The upstream and downstream migration should also be monitored in order to better understand the life-cycle.

LOOK TO THE FUTURE

The main actions that can help to keep viable

populations of the *B. rousseauxii* are:

- It is important to keep free from dams all principal channels of the river and large tributaries that provide habitats necessary for the "dourada" to complete its life cycle. This would also preserve the flood pulse in the Amazon;
- The main sources of pollution and habitat destruction, including mining activities in the river channel and the agrotoxic contamination in the headwaters, must be addressed;
- Increased protection of recruitment areas in the estuary and spawning areas are essential, together with careful management of the fishing.

Finally, the protection of the wide home-range of "dourada", covering several countries, would also secure the preservation of many other species in the catchment. *B. rousseauxii* therefore represents an important 'umbrella species'.

ARTWORK BY ANA LETICIA RAUBER *Modified from a photo by Enrico Richter.*



ΓΧΔΜΡΙ Γ

Development of the Swimway Wadden Sea Programme

Authors:

Country:

Martha Buitenkamp¹, Kerry Brink², Michiel Firet¹ & Wilco de Bruin¹ Organisations: ¹Programme towards a Rich Wadden Sea & ²World Fish Migration Foundation The Netherlands, Germany and Denmark



'Swimway' is the term given to a migratory route used for fish migrating between the source and sea and even across oceans. The global concept of Swimway is an active approach to managing entire habitats for migratory fish species and the ambition is to promote understanding and recognition of the needs of fish across all regions. This can be done in practice through the overarching framework of Swimway Programmes. These programmes can vary significantly from region to region or from species to species, depending on the focus and goals of each discrete Swimway Programme. In the case of the Swimway Wadden Sea Programme, the Swimway is specifically developed for the cross-border Wadden Sea region.

In the Wadden Sea, there are about 150 fish species that contribute an important part of the ecosystem. Many of these species spend only a part of their lives in the Wadden Sea, as juveniles or adults, moving in search of food, spawning or en route between marine and freshwater habitats. In the Quality Status Reports (Tulp, et al., 2017), fish populations are reported to have steeply declined in recent decades due to largely unknown reasons. This could be related to various impacts from climate change, barriers for migratory fish, lack of estuarine habitats, freshwater connectivity issues, predation from seals and cormorants, sand replenishment, recreational boating, fishing and industrial

discharges. Relative quantification of these is lacking due to limited data.

This has highlighted the need for a regional plan to be developed that will take action to improve the current ecological status of fish in the region through a Swimway Programme.

WHAT DID WE DO?

Based on the Quality Status Report in 2010, Danish, Dutch and German fish experts developed conservation objectives for fish, called 'Trilateral Fish Targets', which were adopted as part of the revised Wadden Sea Plan in 2010 (Walker, 2015).

At a ministerial conference in 2010 Denmark. Germany and the Netherlands agreed to advance and implement these targets. As a first step, in 2014 the three countries agreed to develop a trilateral Swimway Wadden Sea programme 2018-2024. This programme involves steps to operationalize the Fish Targets of the Wadden Sea Plan 2010 by setting clear courses of action to guide the implementation of programmes dedicated to achieving the approved targets.

Since then an Action programme has been developed with the input from a trilateral network. This includes a core group of 11 Dutch, German and Danish organisations as well as a network of 60 experts working and commited to Wadden Sea. The purpose of this Action

Programme is to develop a plan to maintain and improve fish populations in the Wadden Sea through research, monitoring, fundraising, communication, and education.

HOW DID IT WORK OUT?

The Swimway Wadden Sea Programme Action Plan will be launched in 2018, during a Ministerial meeting, and a 6-year programme will then be implemented. The goals are to develop projects within this period and to connect with current projects toward a common goal of "no humaninduced bottlenecks in the Wadden Sea for fish populations or their ecosystem function." Currently there are many projects, organisations and managers working toward understanding the Swimways in the Wadden Sea. For example, in the Netherlands projects include long-term fish monitoring programmes, the Dutch Program Ems Dollard 2050 for restoring the ecological quality of the estuary and the Bokkepollenpolder rehabilitation project that rehabilitates the salt marsh with habitat for key fish species. There are also numerous projects in Denmark and Germany such as the Danish fishermen citizen science project and the Masterplan Ems project with Smelt as target species in Germany. In addition to these there are numerous projects being developed such as the Fish Migration River project.

The Swimway Progamme is intended to serve as an umbrella to connect all these activities and direct them toward a common vision.

LESSONS LEARNED

The key to success of the Swimway Wadden Sea Programme is the collaboration with the many existing or planned activities within the region. Within the development process of the action plan it was recognized that

NOORDPOLDERZIJL

Pumping Station Noordpolderzijl is one of over 30 pumping stations located on the international Wadden Sea coast. It is equipped with a fish sluice facility to promote the up- and downstream migration of fish. The main target species at this location are three spined sticklebacks, European eel and smelt. © Herman Wanningen.



>>EXAMPLE

there is already much being done toward managing the Swimways of the Wadden Sea. It is now time to connect these activities within an overarching Wadden Sea Swimway Programme and to establish a firm and longlasting international coalition of partners willing to improve the management of fish stocks in the Wadden Sea region.

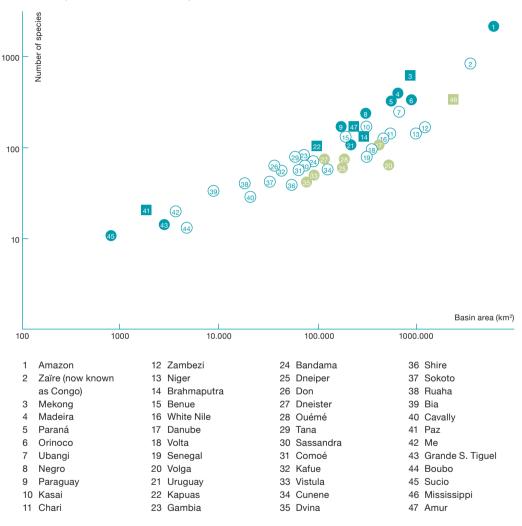
INTERNATIONAL WADDEN SEA

The swimway programme will focus on a set of typical species representing a certain lifestyle in the Wadden Sea region. This includes the European eel, twaite shad, sea trout, smelt, herring, houting, sea lamprey and thinlip mullet. © Satellite image: albedo39 Satellitenbildwerkstatt e.K. (image processing), Brockmann Consult GmbH (scientific consulting), raw data: U.S. Geological Survey. This satellite image is a product of the Trilateral Wadden Sea Cooperation. Fish drawings © Jeroen Helmer.



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).



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 riverbed and the water temperature that prevails during the year. 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 depicts an orderly downstream progression of organisms (Figure 2.1). The diversity of species tends to increase within a basin area at all latitudes, and research by Welcomme (1985) indicated that it does so faster as one approaches the tropics (Figure 2.2).

THE LUANGWA RIVER, ONE OF THE LARGEST REMAINING FREE-FLOWING RIVERS IN SOUTHERN AFRICA

Sililo Agness Musutus (WWF, Zambia)

The Luangwa is a major tributary to the Zambezi River. It was identified within the free-flowing rivers project as one of the last largest free-flowing rivers in Zambia, and is one of the biggest unaltered rivers in southern Africa. Its seasonal changes support endemic and endangered wildlife, vibrant communities, and a growing tourism industry. Not only is it home to one of the highest concentrations of hippopotamus in Africa, and other wildlife, it supports a large diversity of aquatic species, including the newly identified endemic killifish species (*Notobranchius boklundi*) that exists within the floodplains. Unfortunately, the ecosystem services that the river provides are now threatened by hydropower development, deforestation and commercial agriculture. The most imminent challenge is a proposed dam at Ndevu Gorge.

Hippos in the Luangwa River

Zambezi River catchment, Africa. Large wildlife is often in protected nature reserves, which provide a management platform for freshwater ecosystems. © Bruce Ellender.



The Luangwa River during dry season

The Luangwa River is a largely free-flowing river in the Zambezi River Catchment, Africa. © Bruce Ellender.



The Luangwa is one of many rivers in Zambia that will be mapped within the Zambian inventory of free-flowing rivers by WWF. This free-flowing rivers mapping will inform the location of Water Resource Protection Areas, or wetlands that are particularly important for the country's future water security.

CHAPTER 3 MIGRATORY FISH AND THEIR VALUE TO SOCIETY

Tigerfish caught in the Sabie River, South Africa. © Herman Wanningen.

INTRO

The migration of fish up and down rivers and streams is a well-known phenomenon and occurs worldwide. All species of fish migrate at some time in order to reproduce, feed and/ or find refuge. In this book, the term "fish migration" is used for seasonal movements, daily movements and dispersion. It also includes diadromous migrations that some species make between the sea and freshwater river systems. A thorough understanding of fish biology and migration forms an important basis to make the right decisions for the future of fish migrations in our rivers. The knowledge required covers: the life histories of species that undertake migrations, their biology, the reasons why they migrate, the habitats they migrate to and from, and the timing of their migrations. In this chapter an overview of these topics is given.



3.1 MIGRATORY FISH AND THEIR VALUE

The number of freshwater fish species is currently estimated at 15,000 species, of which a significant portion is predicted to have migratory tendencies (Hogan, 2011). It has been estimated that there are at least 1.100 fish species with clear migration strategies required for their survival. A global analysis of the status of freshwater migratory fish showed a 41 percent decline in population abundance in the so-called Living Planet Index (LPI) between 1970 and 2012 (WWF, 2016). This was based on 162 species and 735 populations. Since 2006, there was an increase in the abundance of freshwater migratory fish. which may indicate that these populations are responding positively to strategies and measures to improve water quality and fish passage (Figure 3.1). This LPI will be updated with new data in 2018 and extended by an additional two years. This is to assess how this trend is progressing.

Migratory fish have played an important role in human settlement and have been exploited for several thousands of years as a source of food (Lucas, et al., 2001). In more recent years, the ecological and commercial importance of these species, has led to extensive research and knowledge development. This is particularly true for the large-bodied, predatory species and those that have spectacular spawning runs (Northcote & Hinch, 2004). Table 3.1 presents a summary of some of the more noteworthy facts and figures associated with migratory species.

3.1.1 Ecological value of migratory fish

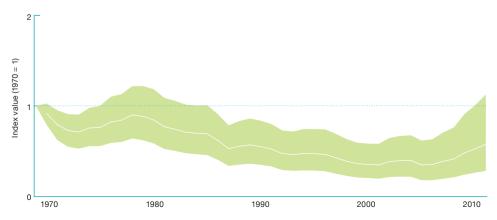
The benefits of sustainable populations of migratory fish can be put into three key categories:

- 1 survival benefits of migratory fish. Migration brings benefits to fish through better feeding and breeding opportunities;
- 2 benefits to the functioning of the entire ecosystem and;
- 3 benefits to humans, through the exploitation of fish and the enjoyment of their existence.

A summary by Morais & Daverat (2006) showed how migratory behaviour inherently creates benefits for the survival of migratory fish species. This includes optimizing growth by accessing more productive areas; improving survival by accessing refugia from severe conditions (e.g., drought, flood, excessively warm or cold water) and predator avoidance; enhancing reproductive fitness by improving adult condition and fecundity; acces-

Figure 3.1

Living Planet Index for migratory fish from 1970 to 2012 (WWF, 2016). The LPI from the 2016 report comprised catadromous, anadromous, potamodromous and amphidromous species as categorised by GROMS (Global Register of Migratory Species).



SPECIES EXAMPLE

Mekong giant catfish (Pangasianodon gigas)

Authors: Organisation:

Country:

Zeb Hogan & Teresa Campbell Global Water Center & University of Nevada, Reno United States of America

The Mekong giant catfish *Pangasianodon gigas* (Chevey, 1930) is endemic to the Mekong River Basin in Southeast Asia. Historically, *P. gigas* occurred throughout large rivers in Vietnam, Cambodia, Lao PDR, Thailand, and possibly Burma and southwestern China. Its ecology is poorly understood, but catch records indicate it uses a wide range of habitats. Juveniles are captured in the Mun and Songkhram Rivers, Thailand and Tonle Sap Lake, Cambodia. Adults are migratory and are believed to move out of the Tonle Sap Lake area into deep waters of the

UNLOADING THE DAI NET

One of the primary threats to Mekong giant catfish is fishing activities. Tonle Sap River fihery, Cambodia. © Zeb Hogan.



Mekong mainstem at the end of the rainy season (October-December) and then up to northern Thailand and Lao PDR to spawn in late May and early June (Hogan, 2012).

Threats

P. gigas is currently listed as Critically Endangered (IUCN, 2011). Fishing, whether targeted or as bycatch, has been until recently the most prominent threat to *P. gigas*. Habitat alteration and migration impediments now pose growing and significant threats. Rapids blasting and port construction in the Mekong River may disrupt spawning habitat, and forest clearing around Tonle Sap Lake will eliminate juvenile rearing habitat. Dams on Mekong tributaries have already blocked *P. gigas* migration routes, but a new threat-dams on the mainstem-will have severe consequences, possibly leading to extinction (Hogan, 2012).

SOLUTIONS

A moratorium on targeted fishing for *P. gigas* since 2008 has likely reduced mortality of adult fish. However, neither abundance nor basinwide harvest is closely monitored, so it is impossible to evaluate the moratorium's impact. Formal monitoring of catches is urgently needed to ensure *P. gigas* is not subject to targeted fisheries and to learn about its distribution, life history, and abundance. *P. gigas* occurs across multiple countries with different development goals, so international cooperation, including a

GIANT CATFISH

Caught on the Tonle Sap River. © Zeb Hogan.



basin-wide management plan, is critical to species protection. Research is needed to identify spawning grounds, migratory behavior, and habitat requirements (Hogan, 2012). Development of an environmental DNA primer specific to *P. gigas* provides a promising new technique to help answer these questions (Eva *et al.*, 2016).

KEY DRIVERS

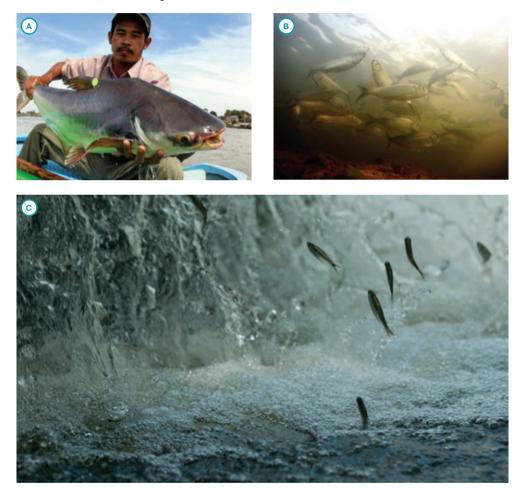
The deep-rooted cultural value, IUCN Red Listing, and iconic status of *P. gigas* have already led to important protective measures (Hogan, 2012). However, the growing human population and shifting socio-economic status in Southeast Asia has increased demand for hydropower to provide energy security in the Mekong River Basin. *P. gigas* will likely face more pervasive environmental threats, and conservation efforts will need to focus on growing impacts from existing and planned hydropower dams and associated economic development (MRC, 2017).

LOOK TO THE FUTURE

Although challenges for *P. gigas* are expected to increase, there is hope for species recovery given the initiation of swift and effective conservation actions. Despite its steep decline in abundance, the available evidence suggests *P. gigas* is still widely distributed, most spawning migrations are intact, all life stages occur in the wild (Hogan, 2012), and its genetic diversity remains relatively high (Na-Nakorn *et al.*, 2006). With increased international cooperation, continued fishing closures, and effective mitigation techniques, *P. gigas* has a chance to persist in the wild.

Diversity of migratory fish

A) Releasing a tagged Mekong giant catfish. Mekong River, Cambodia. © Zeb Hogan. B) An estimated half a million river herring migrate through a fish ladder to spawn in Mystic River, USA. © Beth McBlane & Patrick Herron. C) Fish heading upstream on the Juruena River, Salto São Simão, Mato Grosso-Amazonian States, Brazil. © Zig Koch / WWF.



sing optimal spawning habitats; and recolonizing previously occupied habitats after temporary stock extirpation and re-asserting historic range or expanding into new ranges when suitable conditions develop.

Migratory fish have also been considered as major ecological drivers that can shape the structure

and function of ecosystems (Flecker, *et al.*, 2010). This occurs through provision of benefits through balancing food webs. For example, the large bodied migratory fish such as North American northern pikeminnow (*Ptychocheilus oregonensis*) and African tigerfish (*Hydrocynus vittatus*) play key roles as predators in the food webs. Many hypothesize that migratory fish physically modify

the environment, as well as through nutrient cycling, as important seed dispersal agents and as the movement of biomass and energy from both long distance and short distance migrations.

Migratory fish often have strong biodiversity and cultural values. Despite the relatively small geographic area covered with freshwater (less than 1% of the world's water), inland waters contain 40% of all aquatic species and biodiversity (Carolsfeld, *et al.*, 2003). In the Mekong there is very high biodiversity (estimated between 758 and 1,500 species), a high rate of endemic species, and a high proportion of migratory species (Baran, *et al.*, 2007). This assemblage supports a complex food web that in turn supports the very large populations of people that depend on healthy ecosystems.

The cultural value of migratory fish is often embedded in the history, customs and beliefs of communities that have a daily dependence on fish for meals. There is for instance a strong spiritual, and symbolic relationship between

Table 3.1 Fish facts: some facts and figures about migratory fish

15,000 freshwater fish species	A significant percentage of freshwater fish species are believed to have migratory tendencies.
1 100 migratery field around	
>1,100 migratory fish around	Estimates based on catadromous, potamodromous and amphidromous fish
the world	species from around the world.
41% decline in migratory fish	Abundance of freshwater fish species have declined by 41% between 1970 and
populations	2012, based on 162 species and 735 populations (WWF, 2016)
11,600 km journey in the	Dourada catfish of the genus Brachyplaystoma are known to migrate
Amazon	thousands of kilometres upstream to complete their life cycle. Specifically,
	Brachyplatystoma rousseauxii is reported to have migrated for maximum known
	life history migratory cycle of all size classes of approximately 11,600 km.
48 million people dependent	Millions of people depend on migratory fish as a food source in the lower
on migratory fish in the	Mekong river (Orr, et al., 2012).
Mekong	
\$90 billion fishing industry	Fishing industry in the USA is estimated to be in the billions through commercial
\$55 2	fishing, charter boat companies, manufacturers of fish equipment and more
	(Rubin, 2015).
244 cm/s swimming speed	Rainbow trout are one of the fastest swimming freshwater species (Peake, et al.,
244 cm/s swimming speed	1998).
50% Alaska's fish tourism is	\$150 million dollars is from fish tourism and 17% of population is dependent
from fish tourism	on subsistence fishing. Fishing activities are part of everyday life for 95% of
	population (Macko, <i>et al.</i> , 2017).
1,571 kg, 4.17 m long	The largest record of the anadromous beluga sturgeon in the Volga estuary in
	1827 (O' Connor, 2017). These species are critically endangered.
2.7 m long and 293 kg	The Mekong giant catfish is one of the world's largest freshwater fish (National
	Geographic, 2005).
125 years old	Wisconsin state Department of Natural Resources tagged a 125-year-old lake
	sturgeon (Acipenser fulvescens) in April 2012 (Rose, 2012). The sturgeon was 2m
	and 100 kg.
River herring populations	Due to river restoration of over 3,200 km in the Penobscot River the river herring
grew from 100 to nearly 2	numbers grew from a few 100 to nearly 2 million.
million	
million	

migratory fish and the Passamaquoddy tribe, a tribe of North American Indians in Maine (The Nature Conservancy, 2016). Clan-names in some tribes are associated with diadromous fish; Eel Clan, Salmon Clan, Sturgeon Clan. In other North American Indian tribes, fish migration is actively celebrated during the annual salmon harvests as important ways to pass on traditional values to younger generations. In contrast to this, some cultures are paradoxical, where there is a high dependence on fish and yet a low cultural recognition. Even in these cases where the value of fish is not actively celebrated, fish are still embraced and their value expressed in other ways (Baran, *et al.*, 2007). For example in Cambodia the value of fish is expressed by the number of

Social, historical and economic value of migratory fish

A) Fly fishing in Kulik Lake. Bristol Bay, Alaska, United States. © Paul Colangelo/WWF-US. B) A Carvings depicting mass migration of fish in the Mekong River at Angkor Wat, Cambodia. © Zeb Hogan. C) Fish as a food source, fish drying at a fish market in the Negombo Lagoon, with estuaries of several small rivers including the Ja-Ela River, Sri Lanka. © Wilco de Bruijne.







monuments and statues that symbolise fish. Above all, migratory fish contribute to the natural diversity of fish assemblages, and the healthy functioning of rivers around the world.

3.1.2 Economic value of migratory fish

Fish and fish by-products represent one of the world's most traded products within the food sector (FAO, 2016). Table 3.2 shows the annual consumption of fish around the world. For inland fisheries specifically, the bulk of harvests come from developing countries. In 2014, these countries exported fish products valued at US \$80 billion, which generated revenues higher than all other major agricultural commodities combined. In addition to income generation for developing countries, inland fisheries also play an important role in employment, food security and nutrition. The value of fisheries is easy to monetize directly within the sector, but it also adds indirectly through industry associated with boat repairs, fishing gears, processing of products and transportation and selling of fish.

The fisheries sector provides employment for some 60 million people in both developed and developing countries. Evidently the riverine fishery sector involves a tremendous workforce, producing food where it is greatly needed. Many riverine fisheries are located in areas of increasing local economic development, and often industrialisation. Both stressors compete for water resources and can negatively affect inland water supply and quality impacting aquatic food webs and fisheries they support (FAO, 2010).

Case studies have shown that some fisheries have disrupted migration through the removal of excessively large quantities of fish. This has been significant in Europe, where harvest of glass eel fisheries (Spain, Portugal, France and the UK) and sturgeon fisheries have contributed to the depletion of their respective stocks among the influence of broader environmental changes. Similar excessive levels of exploitation for many other species, notably salmon, have also had serious local implications for stock viability. Agriculture is responsible in many areas for draining wetlands, extracting a tremendous amount of water for irrigation and disrupting connectivity between rivers and floodplains. Floodplains are some of the most productive riverine fish habitats, especially in tropical areas. More than 40% of the floodplains of Bangladesh have been modified and impounded for rice growing, and more than 60% of the water flow of the Ganges Basin is extracted for irrigation and other purposes. This has often resulted in significant societal and economic damage to previously productive fisheries.

In more developed countries such as the UK and US, recreational fishing is a major contributor to the local economy. Recreational fishing is worth approximately £300 million annually to the UK economy (more recent studies are suggesting a significantly higher value), €700 million to the Dutch economy and more than US \$980 million to the Alaskan economy (Peter Gough, 2017, pers. comms.). In the USA a staggering \$46.1 billion was generated by the recreational fisheries with estimates of about 40 million individuals attracted to fishing (Rubin, 2015; U.S. Fish and Wildlife Service, 2017). 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.

3.2 CLASSIFICATION OF DIFFERENT FISH MIGRATIONS

Migration behaviour of fish is typically divided into potamodromous and diadromous groups. This is a classification of fish according to their capacity to live in different habitats at different life stages.

Potamodromous fish 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, but they do not enter the marine environment.

Diadromous species migrate during their life cycle between saltwater and freshwater habitats,

EXAMPLE

Spawning migration behavior of the lacustrine *Labeobarbus* species flock in Lake Tana, Ethiopia

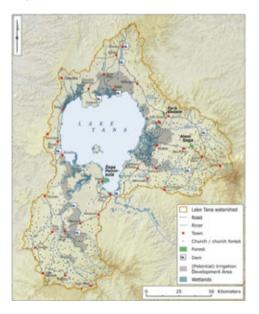
Authors:	Wassie Anteneh ¹ , Eshete Dejen ² &
	Abebe Getahun ³
Organisation:	¹ Bahir Dar University, ² Intergovernmental
	Authority on Development & ³ Addis Ababa University
Country:	Ethiopia



INTRODUCTION

Lake Tana, the largest freshwater lake in Ethiopia (Figure 1) is home to the only intact large cyprinid *Labeobarbus* species assemblage in the country. The main justification for designation

FIGURE 1 Map of Lake Tana.



of Lake Tana as a Biosphere Reserve in 2015 by UNESCO is the presence of this unique fish species assemblage.

The catch per unit effort of the migratory riverine spawning Labeobarbus spp. has drastically declined (> 90% in biomass) during the last two decades, from 63 kg/trip in 1993, to 28 kg/ trip in 2001 and then only 6 kg/trip in 2010 (de Graaf et al., 2006; Dejen et al., 2017). The most likely explanation for this decline is the negative impact of the motorised fishery targeting the spawning aggregations, coupled with irrigation and dam construction causing destruction of breeding and nursery habitats in the spawning rivers. Spawning rivers are disconnected from the lake during the dry season due to excessive water abstraction for irrigation and this has caused juvenile fish mass mortality (Anteneh, 2013).

SOLUTIONS

The spawning behaviors of the species assemblage of *Labeobarbus* species (Figure 2) in Lake Tana (Ethiopia), has been extensively studied for the past two and half decades. Seven of the 15 *Labeobarbus* species described in the lake are known to migrate more than 60km upstream into tributary rivers for spawning

during the rainy season (July to October). According to Palstra *et al.*, (2004), their spawning migration can be partitioned into three stages: 1) migration from the foraging area in the lake to the river mouth; 2) upstream migration along the main river channel; and 3) entering a spawning tributary. After hatching the juveniles stay throughout the year in the pools within the rivers until the onset of the following rainy season (Anteneh, 2013).

WHAT ARE THE KEY DRIVERS?

The three main species groups targeted by current fisheries in Lake Tana are the *Labeobarbus* spp., *Clarias gariepinus* (African catfish) and *Oreochromis niloticus* (Nile tilapia). Of these three taxa, the endemic *Labeobarbus* spp. are the most vulnerable because of their annual migration from the lake to the tributary rivers for spawning (Getahun and Dejen, 2012). The commercial gillnet fishery targeting *Labeobarbus* spp. is highly seasonal and mainly targets the spawning aggregations. More than 50% of the annual catch is obtained in the river mouths in August and September (de Graaf *et al.*, 2006).

The Ethiopian government considers the Lake Tana region a high potential for economic growth, mainly because of its important water resources. Hydropower and irrigation dam construction projects are underway in almost all tributary rivers of Lake Tana. It is expected that these dams will impede the migration of *Labeobarbus* species (Anteneh, 2013). Currently, almost all fishers use undersized stretched mesh size monofilament gillnets. The fishers strongly prefer monofilament gillnets since they are two to four times as efficient as multifilament nets.

The final blow to the lake ecosystem is the infestation of the shore of Lake Tana by water hyacinth (*Eichhornia crassipes*) since 2011. This noxious weed has expanded quickly and now covers more than one-third of the shoreline (Dejen *et al.*, 2017) and it is feared that it will

potentially choke fish migration. Preliminary studies showed that juvenile *Labeobarbus* prefer shores covered by indigenous macrophytes and avoid water hyacinth infested areas.

LOOK TO THE FUTURE

To prevent the collapse of the Lake Tana fishery it is crucial that the existing legislation and management plan is enforced by the local government. It is important to reduce the fishing pressure on the breeding populations, thus, fishing in the inflowing rivers of Lake Tana and the river mouths should be closed for fishing every year from July to October. During dam construction or the diversion of spawning rivers, mitigation measures such as the construction of appropriate and effective fishways or migration channels must be seriously considered. Moreover, unregulated and excessive water pumping by individual farmers from the rivers need to be seriously evaluated as it damages the connectivity of functional habitats.

The 15 Labeobarbus species (heads) of Lake Tana. © Martin de Graaf.

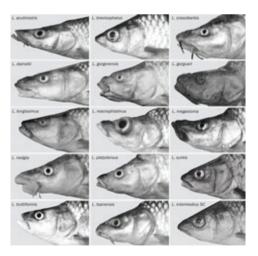


Table 3.2 Global contribution of fish

Overview of world fisheries production and utilization. According to these figures from FAO (2016), the annual fish consumption per capita is steadily growing.

	2009	2010	2011	2012	2013	2014
	WORLD FISHERIES & AQUACULTURE PRODUCTION					
CAPTURE						
Inland	10.5	11.3	11.1	11.6	11.7	11.9
Marine	79.7	77.9	82.6	79.7	81.0	81.5
Total capture	90.2	89.1	93.7	91.3	92.7	93.4
AQUACULTURE						
Inland	34.3	36.9	38.6	42.0	44.8	47.1
Marine	21.4	22.1	23.2	24.4	25.5	26.7
Total aquaculture	55.7	59.0	61.8	66.5	70.3	73.8
TOTAL (million tonnes)	145.9	148.1	155.5	157.8	162.9	167.2

	WORLD FIS	HERIES & A	QUACULTU	IRE UTILIZA	TION	
Human consumption (million tonnes)	123.8	128.1	130.8	136.9	141.5	146.3
Non-food uses (million tonnes)	22.0	20.0	24.7	20.9	21.4	20.9
Population (billions)	6.8	6.9	7.0	7.1	7.2	7.3
Per capita food fish supply (kg)	18.1	18.5	18.6	19.3	19.7	20.1

either for breeding or feeding purposes. 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 streams to lowland rivers, estuaries and coastal waters.

There are different types of diadromous fish migrations, including anadromous, catadromous amphidromous. Anadromous species, and including the salmons and shads, reproduce in freshwater and the juveniles migrate 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 only undertakes limited migrations upstream. As well as coastal marine species such as alewife, which sometimes migrate over long distances, >400 km in some rivers. In the temperate flood rivers of Europe, North America, and Asia, sturgeons (*Acipenseridae spp.*), lampreys (*Petromyzontiformes*), shads (genus *Alosa*) and salmonids (*Salmonidae*) are the main anadromous fishes. Anadromy is rare in some parts of the world; in Southern Africa there are no known anadromous species.

Catadromous species, such as the freshwater eel, enter freshwater as juveniles where they grow to maturity prior to their return migration to saltwater for spawning. There are 16 different eel species around the globe. Many of them are rare and found in the tropical regions of Africa and Asia. Notably there are no catadromous eel species in most of South America. Eleven eel species have a noted conservation status, some of which include the African mottled eel (*Anguilla bengalensis*), Philippine mottled eel (*Anguilla luzonensis*) and Celebes longfin eel (*Anguilla celebesensis*). The species with high commercial and cultural importance are from the temperate zones, including *Anguilla anguilla* (the European species, which extends its range from Iceland to North Africa), *Anguilla rostrata* (the American eel) and *Anguilla japonica* (the Japanese eel).

Figure 3.2 demonstrates the catadromous life cycle of the European eel (European and American eel) and the anadromous life cycle of Atlantic salmon in the North 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 if connections to the sea are restored.

Eels are not the only species that move into freshwater systems from a marine environment. There are many species of marine origin that migrate into the lower reaches of rivers to feed, for example during the dry season, and then return to sea during the rains or other seasonal cues (Welcomme, 1985). Amphidromous species such as flounder (*Platichthys flesus*), 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.

It should also be noted that not only fish species rely on free-flowing rivers for life history migrations.

A diversity of other wildlife also migrate as diverse as manatee's in the Gulf of Mexico and anadromous shrimp on some Caribbean islands. For the purposes of this discussion here, fish migrations will be the focus.

3.3 PURPOSE OF MIGRATION

For most fish species, migration is critical to their survival. For some it is a significant part of their reproductive cycle, such as river herring, sturgeon and eels while for others it may simply be opportunistic for daily feeding and seasonal movements. Here we describe some of these processes.

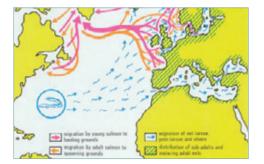
3.3.1 Migration to reproduce

Migration for the purposes of reproduction is generally a seasonal event which forms a fundamental part of the life cycle strategy of most fish species. Migration is usually triggered by seasonal cues in conjunction with maturation, and is often driven or correlated to environmental factors including increased flows and water temperature (Carolsfeld, *et al.*, 2003).

The simultaneous response of all individuals result in spectacular migratory events as the population assembles at spawning locations or before surmounting migratory bottlenecks such as waterfalls. Although migrations are often synchronised, not all movement of fish involves the aggregation of specimens in high concentrations.

Figure 3.2 Migration patterns

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





EXAMPLE

Sharing international knowledge of fish passage in the Lower Mekong

Authors:	William Rice ¹ &
	Lee Baumgartner ²
Organisation:	¹ US Fish and Wildlife Service
	National Fish Passage Program &
	² Charles Stuart University, Australia
Countries:	USA and Australia



THE LITTLE FISH THAT SUSTAIN © William Rice.



INTRODUCTION

As infrastructures ages or new structures are proposed, awareness of the importance of fish passage has gained momentum, most recently in the Lower Mekong River Watershed of South East Asia, composed of five nations; Thailand, Cambodia, Vietnam, Lao PDR and Myanmar. Freshwater fish provide the primary source of protein for more than 60 million residents of the Lower Mekong. Much of this resource derives not from the mainstem of the Mekong River but from thousands of tributaries and far smaller waterbodies that traverse the region. These water bodies are increasingly fragmented by weirs, dikes, dams, road prisms, and associated water management structures, mostly associated with agricultural development and local flood control activities. In a land of tens of thousands of constructed barriers, only an estimated 35 fish passage structures exist across the five nations. As these nations move forward to address the issue of fish passage, sharing international knowledge has never been more important.

WHAT ARE WE DOING?

The U.S. Department of Interior International Technical Assistance Program (DOI-ITAP) is currently collaborating with the U.S. Agency for International Development on the Smart Infrastructure for the Mekong Program (SIM), which seeks to provide technical assistance to lower Mekong nations in addressing the environmental and social dimensions of infrastructure development. Under SIM. the Lower Mekong Fish Passage Initiative utilizes teams composed of fish passage experts from the United States Fish and Wildlife Service and the Australian Center for International Agricultural Research (ACIAR). Building upon a decade of success by ACIAR in Lao PDR, our goal is to replicate and scale up the catchment-level barrier inventory process already undertaken in Lao PDR to other Mekong nations. After completion of an inventory and prioritization process, we will construct and assess the effectiveness of a series of demonstration fish passages in each nation.

We hope this project enhances expertise and awareness of the impact of small scale fish passage barriers, fish passage design, construction, and monitoring across the Lower Mekong. In 2017 the Initiative conducted a planning workshop with representatives of the five nations. In 2018 the Initiative conducted training workshops to train teams from each nation to identify, assess and prioritize fish barriers. Once trained, the next step will be to identify a watershed in each nation that, the local team will conduct as-

CONE FISHWAY CONSTRUCTION IN LAO PDR © William Rice.



FISHING VILLAGERS IN LAO PDR © William Rice.



sessments and, through analysis, select a barrier to be removed or retrofitted for fish passage as a demonstration project. The United States and Australian expert team will work with local designers and builders to construct and monitor the project, which the governments can showcase so that others can learn what fish passage is and its effectiveness in maintaining sustainable fishery populations. It is anticipated that design and construction will take place by the end of 2019.

LESSONS LEARNED

Success in changing opinions of water use to include fish and the aquatic system depends on both the realization that water can still be used for its intended use as well as for sustainable fisheries and that both are important economically.

Short distance migration

Short distance migration is also important. In the lower Rhine River, large schools of juvenile fish, mostly consisting of common roach, migrate from floodplain lakes into a connected channel at dawn and return to the lake at dusk (Heermann & Borcherding, 2006). A) Common roach and common rudd foraging on a flood plain pool. © Blik Onder Water. B) Side channels and floodplains of the River Rhine, Ruimte voor de Rivier programme, Netherlands. © Blik Onder Water.





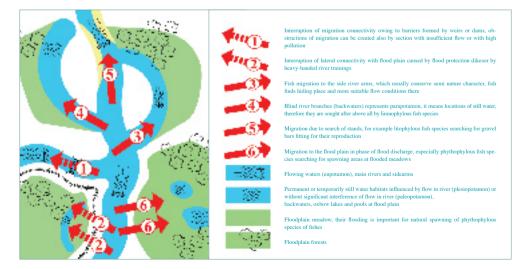
Upstream spawning migration is a critical strategy to maintain optimum distribution of a species in a flowing water environment. The distance of migration varies between species, within populations of the same species, and sometimes within one population of a species that may demonstrate fidelity to one specific location within a river. Some migrations of fish involve distances of thousands of kilometres and can entail prolonged residence in different habitat types. For example, the sockeye salmon (Onchorynchus nerka) makes an extensive migration of more than 3.000 km up the Yukon River (USA and Canada) while on the other end of the scale the whollyfreshwater crucian carp (Carassius carassius) of Lake Kerkini (Greece) migrates less than 1 km up the Kerkinitis River to spawn.

In the tropics, the general pattern for reproductive migration is an upstream spawning migration, followed by a downstream dispersion of eggs, larvae and maturing adults into floodplain areas where growth and maturation occur (Carolsfeld, *et al.*, 2003). Downstream spawning migrations are demonstrated by catadromous adult fish migrating to their breeding areas in the ocean. Post-spawning anadromous adults that are iteroparous (meaning they spawn more than once, as compared to semelparous like many salmon and sea lamprey where all the adults die after spawning), also migrate out to sea. Freshwater potamodromous species and the downstream recruitment of juveniles also migrate downstream.

These downstream migrations have generally not been studied to the same extent as those associated with upstream spawning migrations, but can be equally affected by loss of habitat, habitat fragmentation by dams (especially hydropower dams with turbines), discharge modification, water quality changes and increased rates of predation in impoundments (Marmulla, 2001). There is increasing evidence that the lighting associated with road crossings and general increased urbanization along rivers can delay downstream migration.

Figure 3.3 Lateral and longitudinal migration

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



3.3.2 Additional reasons for migration

In general, food availability, the search for optimal habitats, refugia and predator avoidance can all result in small scale daily movements. Sometimes this can lead to fish swimming large distances, to resolve food demand, the population size and availability of food. A general model of fish behaviour in which fish move between suitable habitats is illustrated in Figure 3.3.

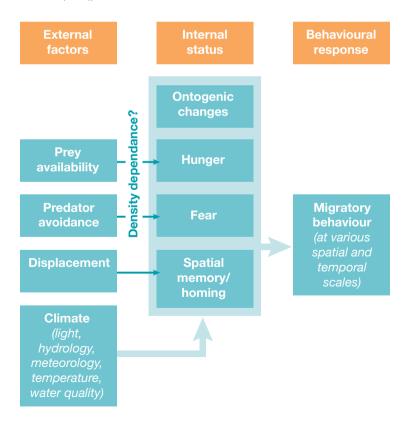
Fish also undertake movements that could be classified as migration to escape threatening environments, often seasonal in nature, including low river flow and seasonal drying of river sections, high water temperatures, and low oxygen concentrations. They may also occur as a result of human activities such as damming, water withdrawal for agriculture and transportation, thermal loading from power plants, waste treatment and other types of pollution.

These circumstances affect the survival of fish populations and are perhaps more correctly classified as 'dispersion' when they are in one general direction verses a regular repeated journey. Dispersion is more a local phenomenon than a fundamental population-scale migration.

3.4 TRIGGERS OF MIGRATION

Both internal and external cues interact together to stimulate fish migration (Lucas, *et al.*, 2001). Not only are there strong influences by external





(Source: Lucas et al. (2001)).

factors such as dispersion and displacement, predator avoidance, prey availability and seasonal factors, but also internal genetic and developmental or life history triggers (Figure 3.4). This interaction between internal and external factors determines whether a fish will migrate or not.

Perhaps the most obvious external factor resulting in fish migration are seasonal (climatic) cues that influence internal developmental responses associated with reproduction and spawning. Larval dispersion of most species of fish commences immediately after hatch. which in Europe occurs mainly in late spring and early summer. 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). Other dispersal movement of adults depends on various other external factors and can occur at any time during the year. In salmon, the seasonal cues are fundamental as they govern the onset and rate of maturation. Salmon and many other fish react to additional seasonal triggers for migration to optimum habitats, synchronising their arrival in appropriate habitats at the optimum time for spawning and transitions from their freshwater to saltwater physiology and back.

The precision to which they "home" to spawning habitats can be an important strategy in maintaining an individual's genetic fitness through preservation of adaptations to local conditions such as a local geography's seasonal hydroperiod, temperature regime, or water chemistry. This internal homing instinct can also help fish find their way if involuntarily displaced during flooding. Homing instinct also requires a more acute sense of kin recognition to ensure that inbreeding among closely related fish is minimised.

3.5 MIGRATION TIMING

Spawning and migration events for different

species occur during distinct periods and at different times and places depending on the species, the purpose of migration and relevant environmental or internal cues (Baran & Borin, 2012). For example, external and internal factors contribute to the striped bass (*Morone saxatilis*) migration each spring and summer north along the east coast of the USA to feed. When the temperatures start to drop, the bass move south. Spring spawning migrations are triggered by increasing water temperature and salinity change resulting in bass ascending rivers to spawn.

3.6 FISH MIGRATION ROUTES

As we have seen, the timing of migration depends on the species of fish and their underlying biology and evolutionary background. However, migration is almost always triggered and determined by the purpose of the migration and the local cues that drive it. Fish migration routes become established over the eons and can be very persistent in time.

The remarkable homing instinct of salmon is a prime example. They spend from 1 to 4 years at sea dispersing over very large geographic areas covering thousands of kilometers, often influenced by seasonal oceanic gyres, as they embark on the process of sexual maturation triggering their homeward journey. Using seasonal currents, but triggered and governed in a way that is still not fully understood, the salmon approach their home waters. The remarkable ability to locate their river of origin appears to use some combination of the earth's magnetic field, the chemical smell of their river and pheromones released by other related salmon in the river. In more recent years, it has been suggested that fish imprint on their natal rivers at an early age enabling them to remember environmental conditions from the spawning area. But still today we are not certain about how these mechanisms work.

Studies have also showed the importance of sounds that are believed to trigger the upriver ascent migration in some species including the Ayu (*Plecoglossus altivelis*), a fish native to east Asia (Febrina, *et al.*, 2015).

SPECIES EXAMPLE

Living gold in southern Africa's rivers!

Authors:

Country:

Gordon C. O'Brien¹ & Garth Wellman² Organisations: 1University of KwaZulu-Natal & ²Caleco Capital South Africa

The Orange-Sengu River basin is an iconic southern African watershed that extends over four countries. Prior to the 1950's more than half of the world's gold had been sourced from the basin resulting in widespread pollution (Braune

and Rodgers, 1987). Additional development had fragmented the rivers in the basin and the populations of fishes that occur within it (Braune and Rodgers, 1987; O'Brien and De Villiers, 2011). Large reach-scale facultative potamodroA RADIO TAGGED YELLOWFISH © Francois Jacobs.



mous migrations (> 50 km) of yellowfish (*Labeobarbus aeneus* and *L. kimberleyensis*), our *living gold*, occur (Plug and Mitchell, 2008).

Today more than 100 weirs and dams act as physical barriers to these migrations within the basin. Interestingly, although vellowfish populations have declined primarily due to water quality changes in the basin, the yellowfishes still dominate most of the catchment (De Villiers and Ellender, 2008) and thrive within the new impoundments and in restricted river reaches of the basin (Ellender et al., 2009). Where access to suitable rheophilic habitats, the preferred spawning sites of the basin occurs, recruitment of yellowfish is relatively more successful (O'Brien et al., 2013). Survival of larval, fry and fingerling yellowfish is however highly variable and affected not only by habitat condition and availability, but by predation threats and disturbance associated with activities of human communities (O'Brien and De Villiers. 2011).

An ecological risk assessment demonstrated that if water resource development in the basin continues without adequate resource protection and conservation efforts, viability of the populations will be threatened. If an attainable balance between the use and protection of the river is implemented in accordance with existing legislation, the risk of stressors impacting on the wellbeing of the largemouth yellowfish will reduce to acceptable, low levels. These ecologically important fishes are also economically valuable and supports a dedicated angling industry worth in excess of US\$ 11 million per season in the upper parts of the basin alone (Brand *et al.*, 2009).

Recently in the lower Orange River, a large healthy population of largemouth yellowfish (*Labeobarbus kimberleyensis*) has been discovered and a dedicated angling community is planned to exploit it. Before the fishery is developed, stakeholders have established a holistic conservation plan for the selected reach of about 50 km of river. The aim of this plan is to characterise the largemouth yellowfish resource, its ecosystem

ORANGE RIVER

Orange River is the longest flowing river in South Africa and is home to two yellowfish species that are popular sport fish species. © Gordon O'Brien.



requirements, and evaluate risk associated with eco-tourism and low impact angling activities on the wellbeing of the local yellowfish population. This will result in best practice water resource protection measures for the benefit of the largemouth yellowfish, the Orange River and local communities dependent on the water resources derived from the river.

With the establishment of a low impact eco-tourism and fly fishing programme on the lower Orange River, the plight of this charismatic fish and its ecosystem will receive much needed awareness, and the human and financial resources required to protect it for future generations! We are in a situation where good management can let everyone win!

Figure 3.5

Fish migration routes in the lower Mekong

In the Mekong there are strong seasonal migrations (Poulsen, et al., 2004). Here is an example of the Cirrhinus spp, formally classified in the Henicorhynchus genus. These species are short-lived species that are adapted to cope with the environmental variability in the Mekong. Spawning at the beginning of the flood season and eggs and larvae moving out to floodplains. During the dry season they move out of the floodplains and eventually into the deep pools of the Mekong.



Adult European eel (*Anguilla anguilla*) that travel to the Sargasso Sea, close to Bermuda, do not simply swim the shortest distance. Instead they travel in a more efficient way, using ocean currents that begin west of Africa and help to propel them toward the Sargasso Sea (Aarestrup, *et al.*, 2009). 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. It is believed that this allows the eels to avoid predators and delay sexual development in the cooler waters during the day, while the daily ascent to shallow warm water may help the eels maintain a higher metabolism.

Around the world there are many studies that have mapped the migration routes of a wide range of fish species. One of the largest fish migrations occurs in the Mekong River, in Southeast Asia. Here there are approximately 768 fish species and 165 are migratory (Baran, 2006). Migrations routes have been studied and mapped for about 40 species that migrate in distinct zones within lower, middle and upper Mekong (Poulsen, et al., 2004). The study summarised the cyclic and predictable movements for huge numbers of fish between the annually-inundated floodplains and dry season refugia (Figure 3.5). Cirrhinus lobatus and Cirrhinus siamensis, commonly known as Siamese mud carp, are one of the most abundant fish in the middle and lower Mekona, comprising about 50% of the total catch between November and February.

During the rainy season, they spawn on emerging floodplains but as the dry season begins they migrate *en-masse* from the floodplains into the Tonlé Sap (a seasonally inundated lake) and to the Khone Falls, where large numbers enter the Sesan system. These migrations are strongly influenced by the full moon and thus migrations are synchronized to occur just within a short period of about 5 days.

All migration requires amazing talent, inherited from their parents, to respond to seasonal and environmental cues to trigger and manage their migrations. Whether simply to feeding daily or to take refuge or to undertake a once-in-a-lifetime reproductive event. The stability of these driving mechanisms is not fully understood. If they are sensitive to human interference, as some fear, for example with climate change, then future stability and assurance of these ecosystems and food security for millions of people is an uncertainty.

3.7 MIGRATORY FISH AROUND THE WORLD

Carlosfeld *et al.* (2003) extensively reviewed the current status of migratory fish around the world. The following review draws partly on this material, supported by biogeographic reviews by local experts.

There is a general theme of stock depletion and reduction in stock ranges, all due to the influence of human activities. This summary strongly supports the necessity of action to ameliorate the ongoing damage to important and often iconic and irreplaceable fisheries resources as we seek to address the threats, including disruption of free migration between seasonal habitats.

3.7.1 Europe

Perhaps the most well-known migratory fish of Europe today is the anadromous Atlantic salmon (*Salmo salar*). Wild populations of the salmon persist in northern Europe, Iceland, Greenland, Canada and the USA where some runs remain strong, but many are not (www.nasco.int). The species has vanished from at least 300 rivers in North-Western Europe, and appear to be about

Atlantic sturgeon (Acipenser sturio)

The Atlantic sturgeon can migrate up rivers for more than 1000 km without feeding.



to disappear from Estonia, Portugal, and Poland. The principal reasons for this decline, and the decline of many other migratory fish populations in Europe, include (a) the obstruction of their migratory pathways into and within rivers; and (b) degradation and alteration of rivers, and in several cases in the past, overexploitation in their homewaters and in distant water marine fisheries. The mortality of salmon at sea is a critical factor and is currently at its highest rate since river records began, and is probably a result of climactic change in the northern ocean and its effect on the food web. Norway, Iceland, Ireland, and Scotland now have, between them, almost 90% of the worlds known healthy salmon populations.

In some parts of Europe, including Denmark, Sweden and the British Isles, an anadromous form of the trout (Salmo trutta), the sea trout or brown trout, is locally, highly significant for the sport fisheries it supports. For example, on the Danish Island Fvn. where sea trout have been carefully managed in the local rivers over the past 20 years, a programme of habitat restoration and weir removal is in place although ongoing stocking of hatchery fish is needed to maintain the fishery. As a result, the Island Fyn has seen an increase in tourist visits and is now one of the top locations in Europe for sea trout sport fishing. In Sweden, two thirds of the stocks of brown trout (Salmo trutta) have become extinct in Lake Vänern due to migratory obstructions. In most other countries, sea trout management includes careful control of exploitation rates by net and rod fishermen in order to maintain stock sustainability while natural river function is restored.

Another commercially significant migratory species in western Europe is the European eel (*Anguilla anguilla*), a catadromous species that spawns in the Sargasso Sea. Stocks have declined over the last fifty years and important mitigation measures on overexploitation are now implemented on a continental scale through a European Commission Directive and national regulatory controls.

The once common Atlantic sturgeon (*Acipenser sturio*) is now critically endangered across Europe. The last population in western Europe is located in the Garonne River in France. Recent re-introduction programs have been started in the Elbe and Rhine rivers in Germany. In May 2012, WWF, ARK for Nature and the Dutch Angling Association released young Atlantic sturgeon into the Rhine River.

In eastern Europe, the beluga (Huso huso), Russian sturgeon (Acipenser guldenstaedti), sevryuga. (Acipenser stellatus), and the sterlet. Acipenser ruthenus, have all been heavily exploited for their roe (caviar). In Poland, the Warta River was dammed, contributing to the disappearance of the anadromous Vimba bream (Vimba vimba), while in Russia, dams have blocked sturgeon spawning migrations. In the Mediterranean, diadromous fish were present in the past although most are now 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).

Other migratory species comprise 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.

Other amphidromous 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 feeding habitats there.

3.7.2 Asia

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. In Northeast Asia, the same Pacific salmon (*Onchorynchus* spp.) found in North America occur alongside

another species, including the cherry salmon (*Onchoryhnchus masou*), which occurs only in Asia. In the South and Southeast of Asia, 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. The livelihoods of many has however been damaged by intense pressure from the human population including the construction of dams and other structures.

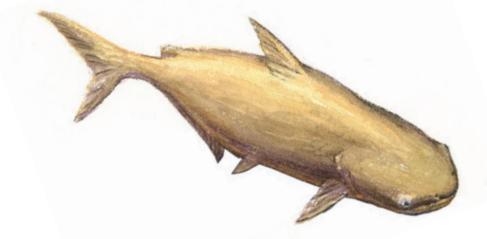
For much of their northern range the salmonids are relatively unaffected by the pressures of development, while to the south there is much greater impact. In excess of 98% of the salmonproducing rivers of Japan have been impacted by dams and other modifications and most fisheries are now dependent on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

In the great rivers of South and Southeast Asia, such as the Mekong, there are some similarities in the fish life history strategies to those of fish in South America and Australia. There are almost 1,000 fish species in the Mekong system, and many of them migrate to spawn at the onset of high waters. After eggs hatch the floods carry the larvae downstream and then juveniles actively migrate upstream into the floodplain nursery areas. The Mekong fisheries are partly based on migrating fish, such as the *dai* (bag net) fisheries in Cambodia and the Khone Falls fishery in the Lao PDR.

Since the 1950's, nearly 6,000 dams, reservoirs and irrigation schemes have been built in the Mekong system alone. In recent years, there has been a further boom in dam development on the Mekong, with more than 700 dams being developed or planned (CGIAR, 2016), most of which are being built for hydropower or irrigation services. These dams change the flow patterns of rivers, fragment the aquatic habitats and block access for thousands of migratory species to spawning and nursery areas. Notably, the Mekong giant catfish (a critically endangered

Mekong giant Catfish (Pangasianodon gigas)

The Mekong giant catfish is the largest freshwater fish in the world and is endemic to the Mekong River. It migrates huge distances to spawn and can grow up to 300 kg.



species found only in the Mekong River and its tributaries) is becoming increasingly threatened by these barriers together with impacts from overfishing. In the breeding season, they migrate out of the Tonlé Sap Lake at the end of the rainy season and are found in the mainstream Mekong in Cambodia, Thailand and Lao PDR. In northern Thailand they tend to spawn at the beginning of the rainy season. The population appears to be panmictic, thus there is enough interbreeding between individuals throughout the basin to yield one apparently genetically uniform population.

In China's East River, a tributary of the Pearl River (also known as the Guangdong River), Chinese shad (*Macrura reevesii*) had virtually disappeared by 1970, their migrations blocked by dams. On the Qiantang River, dammed by the Fuchunjiang, Huanzhen and Xianjiang dams, the shad has vanished, while the number of other fish species in the Xianjiang Reservoir fell from 107 to between 66-83 as the dams were developed that blocked incoming migrations of fish.

In the Yangtze River, populations of two of the largest species in the Yangtze, the Chinese sturgeon and Chinese paddlefish, have declined

sharply in recent years. It is possible that the Chinese paddlefish may be extinct. The once famous Yangzte River dolphin was announced extinct in 2006 (Choi, 2007). The Chinese shad is also now rare, and the reservoirs and dams have stopped the migration of other fishes, shrimps and crabs. Downstream of the Gezhouba Dam on the Yangtze (Changjiang), fish migrations have been severely affected. The China Three Gorges Dam is currently the largest hydropower station in the world. Important local species including silver carp (Hypophthalmichthys molitrix). bighead carp (Aristichthys nobilis) and black carp (Mylopharyngodon piceus) are found in the river and it is feared that the dam will disturb distinct genetic stocks of these species.

In Malaysia, on the Perak River, the Chenderoh Dam has blocked the migration of isok barb (*Probarbus jullieni*) contributing to a decline in their numbers.

The Ganges River or Ganga in India 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

SPECIES EXAMPLE

Ayu (*Plecoglossus altivelis*, Temminck et Schlegel, 1846)

 Authors:
 Keiko Muraoka¹ & Shinji Fukuda²

 Organisations:
 ¹Public Works Research Institute & ²Tokyo University of Agriculture and Technology

 Country:
 Japan

The aju (*Plecoglossus altivelis*), also known as the sweetfish, is a relative of the smelts (order Osmeriformes) and is native to the Pacific in East Asia. Ayu populations are distributed between southern Hokkaido, Japan, and northern Vietnam. They are amphidromous fish, spawning on river gravel in the lower reaches of rivers in the fall. The juveniles drift downstream as soon as they hatch, when they are about 10 mm in body length (BL) and have poor swimming capabilities.

Their downstream migrations takes place at night in order to avoid ultraviolet rays. Once in the sea, the fish stay in coastal regions until the following spring and then, at approximate BL of 5 to 6 cm, the fry migrate towards the upstream reach of the river. Here they continue to develop, feeding on the algae growing on stones. Ayu are seasonal migrants attaining a maximum body size as adults of 10 to 30 cm BL, the actual maximum size varying depending on the river environment. The adult fish die after spawning.

There are also a few landlocked populations of ayu in Japan. These are found in lakes, such as Lake Biwa, and in dam reservoirs.

At the beginning of their life cycle, within a few days after hatching and before their remaining yolk runs out, ayu juveniles must reach the estuary. However, artificial structures have profoundly influenced the downstream migration of ayu juveniles through decreased flow velocity through series of reservoirs. In addition to flow velocity, changes to intake structure and operation must be considered carefully to secure improved survival rate during downstream migration. Unfortunately, not all intake gate operations are effective in Japan. The weak swimming performance of juvenile ayu means that they cannot easily withstand strong abstraction flows. Gate operations are therefore planned to create routes through reservoirs to maximize safe downstream migration of the juvenile fish.

Ayu start migrating back to the river at the fry stage when their bodies are still small. This means that their swimming performance is weaker than the better known salmonid species, even though their swimming physiology in relation to their body size is equal to or greater than salmonid species. The upstream migration of ayu fry is often influenced by artificial structures in the downstream reaches of rivers. Good fish passage design can enable these weak swimmers to migrate upstream by creating a gentle flow rather than the stronger flows generally preferred by salmonid species.

In Japan, ayu is one of the most commercially important food species. They have also been used for religious services. For commercial purposes, ayu fry from other river basins have

COMMERCIAL VALUE

Ayu is one of Japan's most commercially important food species.



been released across Japan. Also, there have been considerable efforts to maintain local ayu populations, for example it is now possible to produce completely farm-raised ayu in each river basin. Furthermore, there have been major attempts to conserve the native ayu population as a symbol of the river environment in many different rivers in Japan. Now, river restorations including fish passages are being implemented to enable ayu to complete their life cycle, migrating from the river to the sea, and to the river again.



Taimen (Hucho taimen)

The taimen is the largest salmonid in the world and the dream catch of every fly fisher. The biggest Taimen ever caught had a length of 210 cm and weighed 105 kg.



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. The widely distributed species of mahseer (Tor tor, also used as a generic name for Neolissochilus spp. and Nazirithor spp.) migrate to the upper reaches and tributaries of the rivers, 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 anadromous ilish, or hilsa shad (Tenualosa ilisha) supported important fisheries but is now seriously affected by dams. For example, in the Indus, upstream impoundments affect flow and access and the species is now nearly extict.

3.7.3 Russia

The Azov-Black Sea basin and the Caspian basin are located in the European part of Russia. A large variety of migratory fish live there, belonging to seven different families:

- Acipenseridae (Acipenser gueldenstaedtii; A. stellatus; A. ruthenus; A. sturio; A. nudiventris; Huso huso);
- · Clupeidae (genus Alosa);
- · Petromyzonidae (Caspiomyson spp.);
- · Salmonidae (Salmo trutta);
- Cyprinidae (Vimba spp., Abramis spp., Rutilus spp., Blicca spp., Cyprinus spp., Pelecus spp. and others);
- Siluridae (Silurus);
- · Percidae (Sander spp.).

Spawning grounds of some anadromous fish species were largely lost as dams built on the main rivers completely cut off fish migration routes. For example, in the Volga River *Stenodus leucichthys* and *Huso huso* lost all access to their spawning grounds. Overall, dams and poaching activity are the main stressors that have led to a reduction of numbers of commercial fish species.

In basins of the Baltic Sea, the Barents Sea and the White Sea anadromous species of *Salmo salar* and *Salmo trutta* are still widely distributed. Additionally, in the basin of the Baltic Sea *Lampetra fluviatilis*, *Anguilla anguilla*, *Vimba vimba* and *Coregonus lavaretus* are still present. *Coregonus pidschian*, *Salvelinus alpinus* and acclimatized populations of *Oncorhynchus gorbuscha* (pink salmon) are found in the basins of the White Sea and the Barents Sea. *Stenodus leucichthys* and *Lethenteron camtschaticum* are found in the Northern Dvina River and the Pechora River.

In the Asian part of Russia, Siberia where rivers flow to the Arctic Ocean, the abundance of fish species of the family Cyprinidae is sharply reduced, while the number of fish species from such families as: Coregonidae (*Coregonus muksun, C. peled, C. autumnalis, C. pidschian, C. sardinella, Stenodus leucichthys*); Salmonidae (*Hucho taimen, Salvelinus alpinus, Brachymystax lenok*); Thymallidae (*T. arcticus*) and Osmeridae (*Osmerus dentex*) are now increasing. *Acipenser baerii* and *Lethenteron camtschaticum* occur in all the main rivers. In the east there are populations of burbot *Lota lota*, and also moving from the east and reaching the Lena River the Pacific salmon *Oncorhynchus gorbuscha* and *O. keta* enter the main Siberian rivers. The main channels of the large Siberian rivers are not regulated and so the influence of dams on migration routes of anadromous fishes here are only seen in the upper more westerly reaches of these rivers and in their tributaries.

The eastern rivers of Russia, flowing into the Pacific Ocean, have a very different fauna of migratory fishes. The main component in terms of their abundance and biomass is represented by salmonids (15 species) and, particularly, by the Pacific salmon of the genus *Oncorhynchus* (*O. gorbusha, O. keta, O. nerka, O. kisutch, O. masou, O. tschawytscha, O. mykiss*) and the chars (genus *Salvelinus: S. malma* and *S. leucomaenis*). Their populations successfully reproduce in the local free-flowing rivers, and in recent years catches of these fish species have reached 340–540 thousand tons per year.

The most diverse fish fauna in the far eastern Russia can be found in the Amur River basin with 19 families and 90 species. Among the migratory fish present here are salmon and sturgeon species, *Huso dauricus, Acipenser schrenckii, O. gorbuscha, O. keta, Osmerus dentex,* numerous representatives of Cyprinidae, including representatives of the Chinese fish fauna (*Ctenopharyngodon della, Hypophthalmichthys molitrix, Chanodichthys mongolicus,* etc.). The main chan-

Atlantic salmon (Salmo salar)

Young Atlantic salmon begin hunting for invertabrates within days after hatching, as soon as their body has absorbed the yolk sac.



nel of the Amur River is not regulated, in contrast to its tributaries, and free fish migrations continue here.

3.7.4 North America

This continent probably has more species of anadromous fish than any other. The best known of the migratory fish of North America, are the salmon species. 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 six species of salmon belonging to the single genus *Onchorhynchus*, listed previously for Asian rivers. 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 is a single species, *Salmo salar*, which has been in decline for decades. They are most abundant in the rivers of the Canadian Atlantic coast in the provinces of New Brunswick, Quebec and Labrador. In the USA, there are some residual stocks, modestly increasing as a result of stocking and river restoration programmes in the state of Maine.

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 (*Onchorhynchus 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 (*Atipenser medirostris* and *A. transmontanus*) and the Pacific lamprey (*Lampetra tridentata*). Smelt are found from Northern California to

Migratory fish around the world

A) Russian sturgeon (Acipenser gueldenstaedtii) in the Black Sea near Tendra, Ukraine. © Andrey Nekrasov/WWF. B) Sea lamprey caught for a telemetry study to determine the passability of the Afsluitdijk in the Netherlands. © Ben Griffioen. C) Release of yellowfish (labeobarbus aeneus) tagged for behavioural research in Vaal River, South Africa. © Gordon O'Brien.



the eastern Bering Sea. Green sturgeon, which grow slowly and are highly migratory, exist in the range from Ensenada in Mexico, to Southeast Alaska. White sturgeon, or Pacific sturgeon, is the largest fish found in freshwater in North America, weighing up to 680 kg, reaching 6 m in length and living to an age of more than 100 years. These fish migrate to spawn in the lower reaches of the largest rivers including the Columbia and Fraser. The Pacific sea lamprey is found from Baja California to the Bering Sea in Alaska and Asia. They migrate from the river to the ocean to feed, returning to freshwater a few years later to spawn. On the East Coast of North America, migratory fish species include the Clupeids: alewife (*Alosa pseudoharengus*), blueback herring (*A. aestivalis*), hickory shad (*A.mediocris*), and American shad (*A. 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 spawnin several consecutive years. Other diadromous species include striped bass, the shortnose sturgeon (*Acipenser brevirostrum*), rainbow smelt (*Osmerus mordax*), tomcod (*Microgadus tomcod*), sea lamprey (*Petromyzon ma-* *rinus*), sea run brook trout (*Salvelinus fontinalis*). Migratory fish, Alabama shad, (A. alabamae) is restricted to the Gulf of Mexico basin along with American paddlefish (Polyodon spathula), gulf sturgeon and stripped bass. There are migratory fish like Lake sturgeon (Acipensar fulvescens) that are native to the American Great Lakes and their tributary streams. The only catadromous speciesfound on this coast, the American eel (*Anguilla rostrata*), which spawns in the Sargasso Sea, possibly in the same locations as the European eel. Atlantic sturgeons (*Acipenser oxyrhynchus*) are found from Canada to the Gulf of Mexico.

3.7.5 South America

There are more than 4,000 fish species in South America, more than any other continent (Hogan, 2011). This consists mostly of small bodied fish, but the continent is also home to the world's largest fish species including the air breathing arapaima (*Arapaima gigas*) that migrates laterally between the river and its floodplains, and the long distance migratory goliath catfish (*Brachyplatystoma filamentosum*).

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, although few outside South America will have heard of the surubim (*Pseudoplatystoma corruscans*), the curimba

Piraiba (Brachyplatystoma filamentosum)

This huge catfish uses barbels to find food in the murky waters of the Amazon. It eats mainly fish but stomach contents have been claimed to contain monkeys as well.



(*Prochilodus lineatus*), or the salmon-like dourado (*Salminus basiliensis*) species. These iconic fish of South America are every bit as charismatic as 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 main-stem.

The pacu and tambaqui are generic names for groups of species within the multiple genera of characin. Several dozen large species of characin have 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.

The first stage of the reproductive migration of larger and economically important species, 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 in the Paraguay River basin as the "lufada" and is exploited by seasonal fishermen along with the annual migration of fish upstream between October and March, during the so-called "Piracema". In some states in Brazil, there are fishing restrictions put in place in order to prevent impacts of overfishing during this piracema period.

In the Amazon, the largest river basin in the world (7 million square kilometres), there are two main groups of migratory fish belonging to Siluriforms (catfishes) and Characiforms (charcins). The goliath catfish from the family Pimelodidae is notably one of the Amazons great channel and estuarine predators. They are represented by a paraphyletic group of six extant and one fossil species of the genus *Brachyplatystoma*. *Brachyplatystoma* spp. in particular are known to travel thousands of kilometres upstream to

SPECIES EXAMPLE

The Yatorana (*Brycon amazonicus*): Fish migration in the Madera River

Authors: Organisation:

Jaime Sarmiento¹, Soraya Barrera¹ & Gustavo Rey-Ortiz² ¹División de Peces. Museo Nacional de Historia Natural & ²Asociación FAUNAGUA Bolivia

Country:

INTRODUCTION

Life cycle

The Yatorana (*Brycon amazonicus*) migration patterns in the Madera river can be summarized as follows: migration into the flooded forests during the early flood season, downstream spawning migration into the Madera river during the middle of the flood season, return to the flooded forests after spawning, and massive dispersive movements in the early dry season (Goulding, 1979; Lima, 2017).

Geographic distribution

B. amazonicus is widespread in the Rio Amazonas and Rio Orinoco basins. Its distribution in the Amazon basin encompasses the Madera river up to its upstream reaches, below 190 m a.s.l. in Bolivia and Brazil (Lima, 2017; van Damme *et al.*, 2014).

Human impacts

The Yatorana is among the most important target

THE YATORANA

The Yatorana (Brycon amazonicus) from Bolivia. © Gustavo Rey Ortíz.



fishes of both recreational and commercial fisheries in the Amazon basin (Lima, 2017). At present, the main threat to the species is the construction of hydroelectric dams in the Madeira river, which impede migratory movements of fish towards the spawning grounds in Bolivia. Consequently, there is a very high risk of population reduction or even local or regional extinction (MRE & MMyA 2014). In addition, the Yatorana is known to be very sensitive to anthropogenic disturbances such as the loss of riparian forest, and water pollution (Lima, 2017).

SOLUTIONS

It is crucial for the Yatorana to pass hydroelectric dams in order to reach the spawning grounds in Bolivia. Understanding the efficiency of the fish passage systems will be crucial for the survival of this species.

A political decision is essential for the successful survival of migrant fishes in the Madera river. The success requires a binational approach between Bolivia and Brazil. Currently, the Bolivian government has issued the Sustainable Fisheries and Aquaculture Law, which promotes the sustainable use of aquatic resources, along with conservation policies for the species involved.

Monitoring the effectiveness of the fish passage systems in the Madera River dams is already in progress in Brazil. Likewise, a baseline study was undertaken in Bolivia to establish the state of knowledge of the biology and the fisheries of the species, as a reference for specification of a national program in order to monitor the impacts of the Brazilian dams.

WHAT ARE THE KEY DRIVERS?

The main issue for the survival of this species is the increasing demand for energy and the dams that are already operating in the Madeira River. Monitoring the efficiency of passage systems and the search for alternatives to ensure optimum passage of the species towards the spawning areas will be crucial. In addition, the development of appropriate management plans for the species in both countries, will be important for the survival of the Yatorana.

LOOK TO THE FUTURE

Improving efficiency of the passage systems in the erected dams in the Madera River is essential. The survival of Yatorana will depend on the ability of the fish to reach the spawning areas in the upper Madera river.

Possible measures to achieve the conservation of Yatorana populations include the following:

- Increase knowledge about the efficiency of the fish passage systems;
- · Fisheries management;
- Reducing impacts, in addition to hydropower dams, that threaten the survival of the species.

BRYCON AMAZONICUS

Local fisheries of the Yatorana (Brycon amazonicus) in northern Bolivia. © Gustavo Rey Ortíz.



spawn. They are also known to move downstream through passive drifting and juveniles have been shown to actively migrate to enter nursery habitats in river channels, floodplains and estuaries.

3.7.6 Africa

Two of the largest rivers in the world are in Africa: the Nile which has also been considered the longest river in the world and the Congo. The Congo River is the second only to the Amazon in terms of size and freshwater species diversity. The basin covers 4 million km² and provides habitat for over 1200 fish Species. The Congo River has the highest species diversity of fishes of any freshwater system in Africa. Recent studies have showed that the extremely fast horizontal and vertical currents in the Lower Congo isolate fish populations along the river and laterally across it, thereby promoting diversification of populations over extremely small distances (Harrison, 2016).

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 dam development that marks a significant conflict between economic development on the one hand, and sustainable development on the other. This has led to the formation of the African Rivers Network which is seeking a new appreciation 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 worlds 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.

In southern Africa, dams have prevented or disrupted the migrations of several vulnerable and rare species. In Lake Kariba on the Zambezi River several potamodromous species, such as *Labeo altivelis*, which migrate upriver to breed, disappeared from the reservoir in the early 1980's because of the lacustrine conditions (Kerimuir, 1984). In Mali, in the delta of the Niger River, there are about 130 to 140 species adapted to seasonal and inter-annual variations in water flow. The Markala Dam built in 1943 and the Selengue hydroelectric dam built in 1980 (and renovated in 1996-2001) appear to be rare examples in that they did not affect reproduction of many fishes, as spawning areas are located downstream (Carlsfield, 2003).

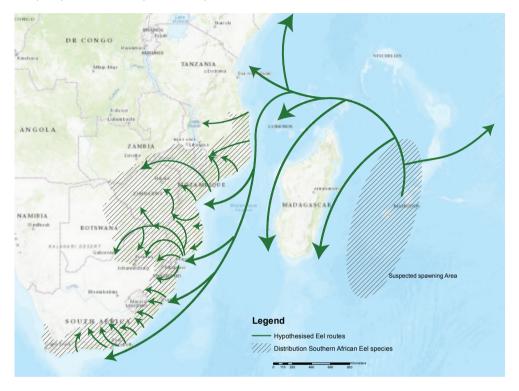
In sub-saharan Africa, the Alistiids migrate seasonally from lacustrine environments to upstream spawning grounds. This includes long distance migration of *Alestes baremoze* and *Alestes dentex* (Leveque, 1997). Similar behavioural patterns have been shown in many different regions throughout Africa from labeo's, to mormyrids and catfish (Bowmaker, 1973). Other species known to actively migrate hundreds of kilometres for reasons other than just spawning include *Hydrocynus* spp. This is a ferocious predator that actively searches for optimal feeding grounds, spawning habitats and water quality.

Lateral migrations onto floodplains are perhaps one of the most common and clear migrations in many African river basins. The Zambezi River has many studies associated with floodplain migration, including literature on killifish species, such as the *Nothobrachius* spp., shown to have the capacity to migrate and colonise pans (Tweeddle, *et al.*, 2014). According to various studies, other lateral migrant species also include the mormyrid species *Marcusenius macrolepidotus, Mormyrus lacerda, Petrocephalus catostama* and *Pollimyrus castelnaui* (Van der Waal, 1996; Timberlake, 2000). As well as other species such as the Hepsetus cuvieri, *Clarias garpiepinus, Schilbe intermedius* and *Microlestes acutidens*.

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 knifefish (*Gymnarchus niloticus*), Senegal bichir (*Polypterus senegalus*) and Peters' elephantnose fish (*Gnathonemus niger*), the reproduction

Figure 3.6

Generalised depiction of the main migration routes of Anguilla juveniles in the summer in Southern Africa as well as the suspected spawning area east of Madagascar (based on Robinet, et al., 2008 and FAO, 1984). Map © ESRI here, OpenStreetmap.



of which is linked to access to the floodplain. Moonfish (*Citharinus citharus*) and widehead catfish (*Clarotes laticeps*), which also use the floodplain, have suffered reductions since their upward migrations have been disrupted.

Labeo altivelis, also known as the rednose labeo, migrate from October to December and spawn between January and March. African sharptooth catfish (*Clarias gariepinus*), a commercially important predatory catfish, moves upriver during the rainy season to lay eggs on vegetation in flooded areas.

Yellowfish species, Labeobarbus spp., are well

Goliath tigerfish (Hydrocynus goliath)

Tigerfish have interlocking, razor-sharp teeth, and are extremely aggressive and capable predators which often hunt in groups. The African tigerfish is reported to attack and catch birds in flight.



SPECIES EXAMPLE

African Longfin eel (Anguilla mossambica)

Author:Olaf LF WeylOrganisation:South African institute for Aquatic BCountry:South Africa





INTRODUCTION

Biology

The long-finned eel *Anguilla mossambica* (Peters, 1852) is found only in the south-western Indian Ocean where it migrates up rivers on the east coast of Africa, Madagascar and the Indian Ocean islands (Jubb, 1964). Adults inhabit many

different aquatic habitats from estuaries to mountain streams up to 1,000 km from the ocean. African longfin eels remain in freshwaters for up to 20 years over which time females grow larger than males attaining lengths of over one meter and weights of up to 5 kg. The eels are predators which feed on aquatic insects, crustaceans and small fishes when older (Jubb, 1964). As is the case with all Anguillids, this species returns to the Ocean to reproduce. It is hypothesized that this species spawns in the Indian Ocean to the north-east of Madagascar, and west of the Mascarene Ridge (Réveillac *et al.*, 2009).

Threats

The African longfin eel has only recently entered the global eel trade with most commercial harvesting being undertaken in Madagascar. Interest and harvests for this species are increasing but data on catch and stock status are lacking (Jacoby *et al.*, 2015). There are no directed fisheries for this species on continental Africa where the main threats are pollution, habitat destruction, the blocking of migration routes by the construction of dams and the introduction of alien parasites such as *Pseudodactylogyrus anguillae* (e.g., McHugh *et al.*, 2017).

SOLUTIONS

Data on distribution, relative abundance and stock status are currently unavailable. Such assessments are urgently required if countries

ANGUILLA MOSSAMBICA After Skelton 2001. © NRF-SAIAB. are to develop proactive policies for effective conservation and management. Current conservation action, such as the legislative requirement for the inclusion of fishways in newly constructed dams in South Africa are however likely to benefit eel populations.

WHAT ARE THE KEY DRIVERS?

As is the case with other eel species, the African longfin eel is threatened by overfishing, habitat alteration, pollution and the introduction of alien parasites (Jacoby *et al.*, 2015). Better legislation regarding sustainable fishing, prevention of the introduction of alien pathogens and maintaining the integrity and connectivity of aquatic habitats is required to secure the future of the African longfin eel.

LOOK TO THE FUTURE

River connectivity is the main issue affecting this and other migratory fishes in Africa. With increased advocacy for the inclusion of fish passages in the construction of dams and with better water management it is hoped that eel populations will be maintained.



Table 3.2

The fish group, extent and location of major freshwater migratory fish families around the world based on information from (Northcote & Hinch, 2004).

Major migratory fish groups	Number of well- showing migrat	General location			
	Amphidromous	Anadromy	Catadromy	Potamodromy	
Lampreys		9		2	temperate
Sharks, rays	10				subtropical, tropical
Sturgeons		10		3	temperate
Paddlefishes				2	temperate
Gars				2	temperate
Osteoglossids				3	temperate
Tarpons	1				subtropical
Freshwater eels			15		temperate,
					subtropical, tropical
Anchovies, shads,	1	22		2	temperate,
herrings, menhaden					subtropical, tropical
Milkfish	1				tropical, subtropical
Carps, minnows				>33	temperate,
					subtropical
Suckers				19	temperate
Loaches				2	temperate,
					subtropical
Characins				>31	subtropical, tropical
Catfishes		1		11	temperate,
					subtropical, tropical
Pikes, mudminnows	1			4	temperate
Smelts (northern)		7		1	temperate
Noodlefishes		>1			temperate
Smelts, graylings (southern)		1		1	temperate
Galaxids		>3	>1		temperate
Salmonids	1	21		34	temperate,
					subtropical
Trout-perches				1	temperate
Cods		1		1	temperate
Mullets	14				temperate,
					subtropical
Silversides				1	temperate, tropical
Sticklebacks		3		3	temperate
Cottids			1*		temperate
Snooks	2				temperate,
					subtropical
Moronid basses		2	1		temperate
Percichthyid perches			1	3	temperate

Major migratory fish groups	Number of well- showing migrat	General location			
	Amphidromous	Anadromy	Catadromy	Potamodromy	
Perches		2*		4	temperate
Tigerperches			1	2	subtropical, tropical
Jungleperches			>2		tropical
Sandperches				1	temperate,
					subtropical
Gobioids	>33	1	>1		subtropical, tropical
Flatfishes			2	>3	temperate,
					subtropical, tropical
TOTALS	>64	>84	>25	>169	

* denotes uncertainty

distributed throughout eastern and southern Africa. This species is a popular fish for recreational and artisanal fishers. They are known to migrate upstream during the rainy season to spawn in the shallow riffles and rapids. They can travel hundreds of kilometres to find suitable habitat and are considered as good ecological indicators and possibly southern Africa's flagship species (Impson, *et al.*, 2007).

In general, there is not much known about the true migratory behaviour of fish species in Africa. Although some work has been done on individual species such as Hydrocynus vittatus (tigerfish) and some Labeobarbus spp. (O'Brien, et al., 2013; Thorstad, et al., 2001; Okland, et al., 2000), very little telemetry and migratory behaviour studies have been published. This includes an insufficient knowledge regarding the four long-distance catadromous eel species in Africa: Anguilla bengalensis, Anguilla bicolor, Anguilla mossambica and Anguilla marmorata. These species all migrate from the Indian Ocean and enter freshwater systems along the East African coastline as juveniles to grow to maturity for 10 to 20 years (Matiza & Crafter, 1994)

3.7.7 Australia and New Zealand

In Oceania, the fish diversity is generally low, dominated by species of marine origin and a

large number of diadromous species (Hogan, 2011). In New Zealand there are approximately 41 freshwater fish species. Seventeen of these are diadromous, including catadromous eels and inanga, anadromous lamprey (threatened Geotria australis), amphidromous galaxiids and bullies (several Galaxias spp. and Gobiomorphus spp.), torrentfish (Cheimarrichthys fosteri), and smelt (Stokellia anisodon). The Atlantic salmon, chinook salmon, brook char, sockeye salmon, rainbow trout and brown trout were introduced and have since been naturalised in New Zealand Rivers. In fact, some of the fishways that were built before the 1980's in New Zealand were intended for salmon and trout, and these became valuable for fisheries (Mallen-Cooper, 1996).

In Australia, the number of freshwater fish is considerably larger including 300 species. Like the migratory fish of New Zealand, many of the coastal regions are dominated by diadromous species. One of the most iconic of these is the barramundi (*Lates calcarifer*), which spawns at sea. During the high tide, the larvae and eggs are washed into the mangroves and tidal habitats and toward the end of the rainy season the juveniles then migrate upstream into the freshwater rivers where they remain. Sub-adult barramundi then undertake a secondary migration upstream into large riverine habitats, where they remain until they become sexually active. Barramundi are an important fish for commercial fisheries, and is farmed in Australia and Asia. Similarly, the catadromous striped mullet is a high value fisheries species in Australia and other regions around the globe.

Other important migratory species in the tropical and sub-tropical regions of Australia include the empire gudgeon (*Hypseleotris compressa*), fork-tailed catfish (*Neoarius graeffei*), freshwater sawfish (*Pristis microdon*), herring (*Potamalosa richmondia*) and long-finned eel (*Anguilla reinhardtii*). In the more temperate zones common native migratory fish species range from the shortheaded lamprey (*Mordacia mordax*), golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), murray cod (*Maccullochella peelii*), to the Australian bass (*Macquaria novemaculeata*), bony herring (*Nematalosa erebi*), catfish (*Tandanus tandanus*) and Australia smelt (*Retropinna semoni*).

Murray cod (Maccullochella peelii)

The Murray cod is the largest native fresh water fish in Australia, although the species is called a cod, it is not related to the marine cod of the Northern Hemisphere.



Gloden Perch (Macquaria ambigua)

This Australian freshwater fish species is found primarily in the Murray-Darling River system. Golden perch are highly fecund. Females can produce up to half a million eggs per spawning event.



The most well-known river system in the temperate zone is the Murray-Darling, which drains the majority of south-east Australia and is the longest river in Australia. In this system, there are about 46 fish species, many of which are either potamodromous or diadromous (Lintermans, 2007). Studies on two of the more important species in the basin, golden perch and Murray cod, showed that these species are severely threatened by instream barriers. For example, the golden perch migration, which has a recorded upstream migration of up to 2,500 km is easily compromised, also because when its larvae drift downstream they can have up to 95% mortality on passage through undershot weirs (Baumgartner, et al., 2006).

CHAPTER 4 GLOBAL THREATS AND CHALLENGES TO FISH MIGRATION

Save our rivers, stop the dam campaign in 2016, Soca River, Slovenia. © Jan Pirnat.

INTRO

Migratory fish populations are threatened all over the world by ever-increasing anthropogenic activities. Although many stressors are being tackled in Europe, North America and Australia, there are many new emerging challenges in Asia, Africa and South America. Physical barriers along with other instream structures that disrupt connectivity, habitat changes that damage fish production capacity, overfishing and the unfolding impact of climate change are among the major challenges that migratory fish face. In this chapter, these threats and their consequences are considered considered in more detail.

ONCE THERE

CRY

ME A RIVER

Sale Viewown 2018/ 2000. 11

WAS AN ICE CAP. NOW THERE'S ONLY AN ICE GAP.

GLOBAL THREATS FOR MIGRATING FISH



4.1 IMPACT TO MIGRATORY FISH

Decision makers are often faced with the major challenges of managing a complex web of natural interactions coupled with anthropogenic activities and emerging ambitions for development that can heavily influence or degrade rivers. In most literature pertaining to migratory fish, the dominant threat is associated with physical instream structures although this is perhaps simply because the impacts are so immediately visible. Apart from the direct and indirect effects of instream barriers, there are numerous other anthropogenic activities that also have a significant impact on fish migrations. Harbour activities can have a significant influence on migrating fish, due to water extraction from adjacent rivers for dock supplies and navigation, increased pollutants, human activity, noise pollutants (Slabbekoorn, et al., 2010) and collisions with ships and their propellers can be lethal (Killgore, et al., 2001). Wherever such generic activities are considered, then implicit risk becomes obvious.

In general, urbanisation and industrialisation influences migratory fish through many mechanisms, ranging from river channel management such as river re-alignment, removal of riparian vegetation, and thermal, organic and chemical pollution to hydrological and sedimentation issues (Fenkes, et al., 2016). These impacts can negatively influence migratory fish in different ways. This includes the impact on individual fish and fish populations as they respond to physio-chemical changes to which they are not adapted (e.g. induced ecotoxicological responses). Barriers also negatively impact fish migrations, causing delay or trapping migratory fish and worsened by many synergistic effects that suppresses normal behaviours and reactions to environmental cues. For example, hypoxic regions have been shown to delay river entry by anadromous fish (Lucas, et al., 2001) thus effectively trapping them temporarily where they may become exposed to further risk or simply miss the triggers that would otherwise stimulate natural migratory behaviours.

4.2 WATER QUALITY AND QUANTITY

Physical and chemical barriers cover a wide range of impacts and effects. They include pollution plumes arising from industrial activities or un-regulated management of human waste, acid sulphate soil discharges, thermal discharges, entry to rivers of agro-chemicals and the impacts these have on water nutrients, phytotoxins (e.g. cyanobacteria) and oxygencarrying capacity.

Influences of urbanisation and industrialisation

A) Fish entangled in filamentous algae produced due to eutrophication, a typical water quality issue due to a high nutrient loading. River Rhine catchment, France. © Wilco de Bruijne. B) Heavy industry on the shores of the Paraiaba South River, Rio de Janeiro State, Brazil. © Edward Parker/WWF.





SPECIES EXAMPLE

Danube sturgeons on the brink of extinction

Author:	Jürg Bloesch
Organisation:	IAD (International Association for Danube Research)
Country:	Switzerland

INTRODUCTION

Of the six native sturgeon species inhabiting the Danube River, one is extinct (*Acipenser sturio*), two are on the brink of extinction (*A. nudiventris* and *A. gueldendtaedti*), and two are critically endangered (*A. stellatus, Huso huso*). The freshwater species, *A. ruthenus*, is vulnerable (Bloesch *et al.*, 2005; Sandu *et al.*, 2013).

In the large Danube River Basin there is a complex range of different pressures (Reinartz, 2002). Over-exploitation, illegal poaching and the caviar trade (despite sturgeon fishery bans in the countries bordering the Lower Danube) are primarily responsible for the ongoing decline of all

BELUGA STURGEON (HUSO HUSO) © Phyllis Rachler, WWF DCP.



Danube sturgeon species. Hydromorphological alterations caused by hydropower development (e.g. the Iron Gates and Gabčíkovo dams), navigation (e.g. the submersed sill construction at the Bala Branch bifurcation), and flood protection measures led to habitat degradation and disruption of the river continuum and spawning migration. While organic and nutrient pollution have diminished, hazardous micropollutants increasingly threaten the Danube sturgeons.

Potential solutions include well-known measures such as ensuring up- and downstream migration by building fish passages across dams that are also suitable for sturgeons (de Bruijne *et al.*, 2014), habitat restoration and protection, cracking down on illegal sturgeon catch and the caviar trade, mitigating technical impacts and pollution, as well as ex-situ strategies including controlled sturgeon propagation and release programs.

SOLUTIONS

- Key research topics encompass the investigation of population genetic structure, stock and habitat assessment, and studies into the behavior and life cycle of Danube sturgeons;
- 2 Policy for sturgeon protection is pursued in the International Commission for the Protection of the Danube River (ICPDR) and documented in the Danube River Basin Management Plans

(DRBMP) that are produced in response to the European Water Framework Directive (EU WFD);

3 In-situ actions are urgently needed, yet are rare or incomplete because of a lack of political will, financial support and, hence, the implementation of measures. Ex-situ conservation can sustain the residual populations by maintaining a genetic pool for stocking (Chebanov *et al.*, 2011).

KEY DRIVERS

- The economy is the key driver for two aspects: first, the development of new infrastructure in Eastern Europe, promoted by the European Commission (EC) and secondly, the lack of funding for sturgeon research and sturgeon conservation measures;
- 2 The EU WFD and related Nature Directives provide key legal drivers i.e. production of

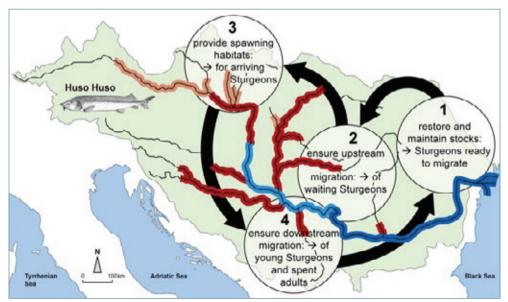
the DRBMP; however, implementation is undertaken by the Danube countries based on national and regional environmental law.

LOOKING TO THE FUTURE

On one side, the ICPDR designs strategies and solutions, whilst on the other hand, research institutions, NGOs and local stakeholders implement projects for sturgeon conservation. Major issues demanding complex solutions are the fish passage constructions at the Iron Gate dams and the mitigation of navigation impacts in the Lower Danube. Transboundary research must be intensified to provide essential facts and knowledge as the basis for sturgeon conservation measures. The political dialogue initiated within the European Strategy for the Danube Region (EUSDR) should be promoted by embracing all stakeholder views and considering social aspects of local fishery communities.

FIGURE 1

Sturgeon Action Plan. The ultimate goal of the 72 actions, grouped into 12 objectives, is to maintain and restore the natural life-cycle of sturgeons using basin-wide conservation measures. Aim: restoration of the natural sturgeon life-cycle requires joint and simultaneous actions in the Upper, Middle and Lower Danube.



EXAMPLE

Fight the power!

Author: Organisation: Country: Mark Lloyd Angling Trust & Fish Legal United Kingdom



The Angling Trust (www.anglingtrust.net) is the representative organisation for all coarse, sea and game anglers in England and Wales. It is joined in a collaborative relationship with Fish Legal (www.fishlegal.net), an organisation which takes legal action against polluters and others who damage its members' fisheries. Shortly after the formation of this new united organisation in 2009, the Environment Agency (the Government regulatory authority in England) decided to promote hydropower on rivers and the government offered generous feed in tariffs to developers. 26,000 sites were identified as having potential for hydropower turbines in England alone, which would collectively cause great damage to fish populations. Hundreds of planning applications were submitted, many of which failed to take the needs of fish into consideration.

The Angling Trust took on this challenge by lobbying government and the Environment Agency to change its policy with the following actions:

 Issuing a position statement to politicians setting out our policy and highlighting good and bad practice;



SAWLEY WEIR

- Publishing a guide to sustainable hydropower for community groups developing schemes in the mistaken belief that they were saving the world;
- Attending meetings of a review group for the EA guidelines to developers which succeeded in reducing the amount of water that could be taken, and requiring better screening for fish. This made many planned schemes unviable;
- Challenging the EA to consider the cumulative impact of multiple schemes on rivers;
- Issuing press releases challenging the EA and government to stop supporting an industry which could only generate 0.1% of the UK's electricity needs;
- Submitting objections to schemes which were badly designed and challenging the EA to ensure that licence conditions were actually met in practice.

Fish Legal took legal action to stop a weir and hydropower installation being built on the River Trent at Sawley, arguing that the structure would impose on its member angling club's fishing rights. The EA agreed a permit for the scheme which would have allowed it to kill up to 100 coarse fish and 10 salmon every day! We won the case and the developers had to pay significant legal costs which led to the company going out of business. It had numerous schemes planned elsewhere in the country which have not gone ahead.

This programme of action, delivered over the course of nearly 10 years, has been successful in that the number of planning applications has dropped very significantly and many rivers which might have had turbines installed are still running free.

Our work continues to ensure licence conditions are met and we have recently highlighted a case on the River Wear where salmon and sea trout were being damaged and killed in an Archimedes screw and water was being diverted into the turbines even at times of low flows. The scheme and its operation are currently being modified.

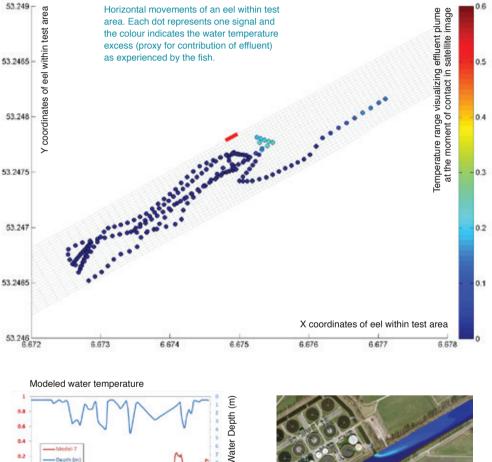
We successfully stopped a rush towards hydropower by greedy developers and misguided community groups, but we will keep fighting to protect fish and fishing from the schemes which have been approved.

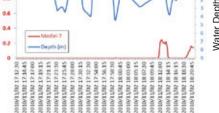


THE GORING HYDRO PROTEST

Figure 4.1

Tagged adult eels migrating to the ocean show how wastewater plumes can act as non-physical barriers for eels (Foekema, et al., 2011). Some of the eels demonstrated significant behavioural changes caused by the discharge of water treatment plant Garmerwolde into the Eems canal (The Netherlands). Although the exact stimuli responsible for the behavioural responses could not be directly identified, there is a clear indication that eels are influenced by changes in water quality.







Areas of low dissolved oxygen have frequently had major impacts on fish populations, notably in and close to urbanised areas. This can result from many anthropogenic activities. Large dams, can create cold water issues through the practice of releasing water from the bottom layers of the upstream impoundment or warm water issues through the practice of top releases. Both can alter temperature regimes downstream and have an adverse impact on the timing of migration and breeding patterns of some fish species. Because of temperature changes, the emergence of salmonid fry has been observed to be asynchronous with other environmental conditions (oxygen levels, prey availability, etc.) that support their development in some examples in Europe. Combustion power stations often require river or coastal water for cooling. This can lead to thermal pollution contributing to aquatic environmental impacts including eutrophication, exacerbation of the impact of other pollutants, adverse impacts on fish migration and for some species direct mortality. Fortunately the better practice of atmospheric cooling of waste water which is more protective of aquatic environments is becoming more common.

Some studies have also shown a direct correlation between changes in river temperature and migration success of sockeye salmon (*Oncorhynchus nerka*) (Farrell, *et al.*, 2008). A study carried out by Wageningen Marine Research, showed how changes in water quality caused by a sewage treatment plan can influence the avoidance behaviour of fish (Figure 4.1).

Chemicals affecting behaviour of smolts

Studies in coastal salmon rivers in eastern Maine, USA suggest that agro-chemicals may be one cause of young Atlantic salmon smolts losing their sense of smell and predator/prey detection particularly when coupled with acidification of the water and therefore increased solubility of aluminium. Photo: Atlantic salmon smolts. © Blik onder water.



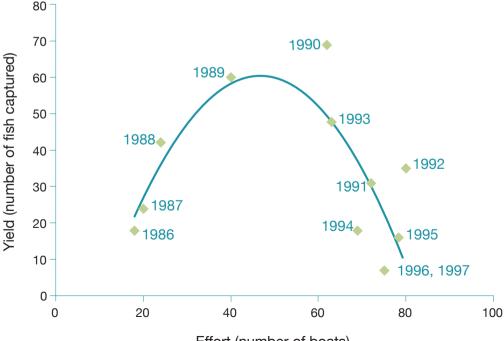
In many cases fish are unable to exhibit effective behavioural avoidance measures from excess temperature, pollutants and various other adverse water quality issues. In such cases exposure to stressors can affect fish physiology and behaviour leading to impacts including suppressed swimming performance, compromised homing ability, predator avoidance, foraging, and spawning site selection. A reduction in swimming performance can, for instance, have a significant effect on migrations. Stressed fish are less likely to overcome the physical demands of passage past man-made and certain natural obstacles, making it less likely to reach prime spawning grounds, or arrive late or out of prime condition for spawning. Other stressors, possibly even angling catch and release techniques (Richard, *et al.*, 2014) may have similar effects. A review of behavioural issues related to toxic substances and other stressors can be found in (Scott & Sloman, 2004; Thorstad, *et al.*, 2008).

Indeed there is a plethora of studies documenting the many stressors that are caused from water quality problems, for example indirect biomagnification of toxicants.

In addition to water quality issues, the amount of water is also a major factor to consider. The abstraction of water from rivers is not always managed in a way to prevent damage to the river hydro-morphological environment and the

Figure 4.2

Consequences of overfishing of the giant catfish in the Mekong. The figure represents how the initial increase in the number of fish captures resulted in steep declines of catch. According to Allan et al. (2005) increases in fishing have resulted in increased catches, but could not be sustained long term. These are data based on the Mekong giant catfish fishery in Chiang Khong.



Effort (number of boats)

fauna and flora that require certain flow bands to facilitate their life cycles.

A comprehensive understanding of flows for fish migration, reproduction and each subsequent life history stage is essential. This must then be used to influence difficult decisions on water resources management. Getting it wrong can have profound impacts, illustrated clearly by examples of rivers around the world that no longer discharge into the sea due to over-abstraction and poor statutory regulation or enforcement of rules.

4.3 OVERFISHING

Fish have always been, and continue to serve as an important source of food nutrition, income and livelihoods for millions of people around the world (FAO, 2016). Overexploitation of resources in fisheries-dependent communities is thus a huge concern as key stocks approach unsustainability. This is particularly the case in tropical regions such as the Mekong and Zambezi, where people are very heavily reliant on fish-based protein and commercial trade. Well publicised examples of this effect are the Mekong giant catfish in Asia and the Nile perch in Lake Victoria in Africa. Stocks of these fish have been heavily over-exploited. Elsewhere there are many examples of fish stock declines. In Australia, Europe and North America migratory fish such as the Murray cod, eel, sturgeon and Atlantic and Pacific salmon have been significantly influenced by overfishing in past years. Allan, et al., (2005) characterised a common pattern resulting from this kind of historical overfishing where high-value stocks are targeted to the point where fish numbers decline dramatically. This is measured by catchper-unit-effort, resulting in changes to stock characteristics including an overall reduced age of maturity and lower size of individuals captured (Figure 4.2). The authors further characterised overfishing of entire fish assemblages, which have major top-down ecosystem consequences. In one example in the North American Great Lakes, the overfishing of lake sturgeon (Acipenser fulvescens), cisco (Coregonus artedi) and lake whitefish (*Coregonus clupeaformis*) resulted in a succession of species collapses in the early 20th century. Another example showed how large species in the Oueme River (Republic of Benin) disappeared due to overfishing and were replaced by smaller labeos, catfish and mormyrids.

These effects may not always be reversible. The result can be profound adjustments to artisanal fishing opportunity and therefore great risks to protein supplies and economies of whole populations. This has led in some cases to additional pressures on agriculture productivity leading to further stress on rivers and their capacity to replenish their fish faunas.

In addition to overharvesting issues for migratory fish, the impact on fish stocks is frequently exacerbated by cumulative and synergistic impacts of pollution, eutrophication, mechanical habitat destruction, introduced species and climate change. It is essential that these risks are understood and considered in implementing effective management regimes.

4.4 CLIMATE CHANGE

The effects of climate change are hard to predict, but rising sea levels, more dynamic storms and droughts, increased temperatures and the way humans adapt will surely change the distribution and composition of fish stocks and their ability to move. Migratory fish are particularly susceptible to risks associated with climate change as the timing of their life cycle transitions are usually finely tuned to environmental cues. Migratory fish are exposed to a range of differing habitats due to the large distances they move.

As summarised in a review by Ficke, et al., (2007), climate change presents fish with new threatening environments. This includes threats resulting from increased temperature, decreased oxygen, increased toxicity of pollutants, the effects of changes of water availability including at times excessive or reduced flows and altered seasonality.

EXAMPLE

Status of floodplain fish assemblages and their lateral migrations in Zambia

Author: Organisation: Country:

Bruce Ellender South African Institute for Aquatic Biodiversity Zambia



INTRODUCTION

Three aquatic ecoregions within the Zambezi River basin in Zambia experience strongly seasonal rainfall, with up to 1000 mm falling between November and May each year; The Upper Zambezi Floodplains. Kafue and the Middle Zambezi - Luangwa (Abell et al., 2008). As a result, the broad areas of grassland bordering the main river channel are seasonally inundated to form a floodplain that can be 30-50 km wide. These floodplains are incredibly productive and support fish assemblages dominated by, but not limited to; cichlids (Tilapia, Oreochromis, Serranochromis. Sargochromis and Coptodon). mormvrids (Marcusenius. Petrocephalus, Pollimyrus) catfishes (Clarias, Clariallabes, Synodontis, Schilbe) and cyprinids (Enteromius) (Winemiller & Jepsen, 1998). A common feature shared by Zambian floodplains is that their fish assemblages migrate laterally from main river channels to inundated grasslands in response to seasonal water level changes. These lateral migrations allow the fishes to exploit ecological opportunities by moving into newly flooded habitat mosaics in the riparian zones to feed and/or reproduce (Winemiller & Jepsen, 1998). For example, 71% of Nembwe Serranochromis robustus radio-tagged in the upper Zambezi moved from the main river channel to adjacent temporary flooded grassland during high water (Thorstad et al., 2005) and both adult

and juvenile African sharptooth catfish *Clarias gariepinus* have been observed up to 30 km from permanent water on seasonally inundated floodplains. Increasingly, however, the lateral migrations of these floodplain fish assemblages are being threatened by unsustainable exploitation and flow alterations resulting in changes to the timing, duration and magnitude of seasonal floods that are the lifeblood of these systems.

THREATS AND IMPACTS

The Kafue River is the most economically important basin in Zambia and supports hydropower generation, heavy industry and a significant fishery. On the Kafue Flats, a 6500km2 floodplain on the middle Kafue River, two large impoundments have been constructed for hydropower at the upper and lower limits of the Kafue Flats - the Itezhi-Tezhi upstream and the Kafue Gorge downstream. This has severely disrupted natural flow regimes and changed the timing of flood pulses; decreased the magnitude of natural flooding; decreased the overall inundated area on the floodplain: and the impoundments have also increased the area of floodplain now permanently inundated. The impacts of these disturbances on fish communities as a whole are largely unknown, however, in conjunction with increasing fishing effort and the use of damaging gears, the total

catch from the Kafue Flats has decreased from approximately 11 000 tons per annum during its peak to 3000 tons per annum currently (Deines *et al.*, 2013).

Traditionally fishers on the Upper Zambezi Floodplains construct earthen barrier weirs on the floodplain during the dry season that can be many kilometers in length (Winemiller & Jepsen, 1998). These barrier weirs are constructed with narrow slotted gaps placed intermittently along their length for fish to pass through during the inundation phase of the floodplain. Once the floodwaters recede, traditional fish traps, colloquially referred to as 'maalelo traps' are placed in these gaps and catch fish moving off of the floodplain back to the main river channel. Unchecked fishing effort means that the number of fishers reliant on the resource and length of weirs is always increasing. Gear technology changes from traditionally using reed basket traps to contemporary practices of lining the reed traps with fine meshed monofilament gillnets or mosquito nets, means that these gears are becoming less selective and fewer fish are now able to make the return trip to the main river channel. As a result of these multiple stressors almost all of the Zambezi floodplain fish assemblages are now severely depleted and have experienced declines in catch rates, a decrease in average size of fishes and in some cases the absence of larger fisheries species from depleted river stretches (Tweddle *et al.*, 2015).

FLOODPLAIN FISH LIFE-HISTORIES

Fish reproductive strategies on floodplains are closely linked to flood pulses (Winemiller & Jepsen 1998; Bokhutlo et al., 2016). Reproductive strategies include mouthbrooding cichlids that gather to spawn just prior to floodplain inundation, and moving onto the floodplain during the flood to release their young and take advantage of feeding opportunities (Winemiller & Jepsen, 1998). In contrast, at the onset of the rains, African sharptooth catfish prepare for spawning and as water levels rise and the floodplains become inundated, so the catfish gather, move into the adjacent delta and spawn in relatively shallow water in submerged vegetation (Bruton, 1979; Bokhutlo et al., 2016). The young thereafter grow exceptionally guickly

LOCAL FISHERMAN

Local fisherman returning from setting their nets on the Kafue Flats, Zambia. © Bruce Ellender.



>>EXAMPLE

OVERFISHING ON ZAMBIAN FLOODPLAINS

A drying rack illustrating the average size of fish that continues to decrease as a result of overfishing on Zambian floodplains. © Bruce Ellender.



in this nutrient rich, newly inundated environment (Bokhutlo *et al.* 2015). Despite the severely depleted state of these fish assemblages, under favourable conditions with proper management regimes, given their life history characteristics of early maturity, high levels of parental care (cichlids) or high fecundity (catfishes) and fast growth (cichlids and clariids), recovery would be fairly rapid.

Zambia recognizes the importance of the flooding season for fish reproduction and growth and institutes a country-wide closed fishing season locally known as the 'fish ban' (Zambian Fisheries Act, cap 22 of 2011; 1st December to 28th February the following year) during the peak fish reproductive period. Closed areas such as the Lochinvar and Blue Lagoon National Parks on the Kafue flats and gear limitations such as gillnet mesh-size restrictions allow for protection and sustainable harvest of floodplain fishes. Unfortunately despite the interventions put in place to manage and conserve floodplain fish assemblages, capacity for monitoring and enforcement is limited, even in formally protected areas and national parks and therefore the resource in most cases can be considered 'open access'.

CURRENT AND FUTURE MANAGEMENT INTERVENTIONS

Currently a number of alternative management tools are being investigated by both the government and NGOs on the Zambezi River system. Community based fisheries management is one such tool that promotes ownership of a resource and allows local communities to be custodians, effectively responsible for the resource management with the incentive of also being the benefactors of the resource. On the Namibian/Zambian border, fish sanctuaries have been established and local community monitors employed to police these. Initial results are promising, however, their long term success remains to be seen (D. Tweddle pers. comm.). Providing capacity for the enforcement of the fish ban and educating communities on the benefits of this closed season has had some success in the Bangweulu wetlands, part of the Zambian Congo river system where following enforcement of the fish ban, fish landings the following season increased (C. Huchzermeyer, African Parks Fish Ecologist, pers. comm.).

Recognition and quantification of the value that these floodplain fish assemblages provide to livelihoods and local, regional and national economies, in contrast to power generation will provide more robust information on the cost/ benefits of river regulation. As the success of many management interventions has been limited, demonstrated by the continual decline in catch rates of floodplain fisheries (Tweddle et al., 2015), novel approaches integrating traditional and contemporary management tools with a balance between top-down control by government and devolving management responsibility to the communities is needed to better conserve these floodplain fish assemblages.

Temperature increases in polar regions are already leading to a range of species and whole food web responses. These could lead to local extinctions due to thermal stress, while in other cases temperature changes may result in dispersal of species northwards to more favourable conditions. In time, there may be genetic changes brought by rapid natural selection (Reist, et al., 2006). In Russian rivers, many species, in the northward flowing rivers, have the potential for significant northward dispersal in response to climate change leading to increased species diversity in some of these areas. There is already some evidence for such northward colonization in the Pechora River and the Sredinnaya Guba estuary where northern pike, ide and roach have become much more numerous.

While increased temperatures and eutrophication can increase productivity of certain species, there is evidence of climate-driven declines from these forces in productivity of other species. For example, shifts in food abundances caused by climatic changes can result in bottom-up impacts on predators, including salmon (Frederiksen, et al., 2006). This has been shown in a study that correlated rising sea surface temperatures in midwinter to reduced growth condition of migratory salmon on their return migration during subsequence summer months (Todd. et al., 2008). Another example comes from the Ontario lakes, in Canada where it is predicted that warming waters will attract normally temperaturerestricted smallmouth bass. This would likely result in an excessive abundance of this large predatory species with resulting impact on four native cyprinid species (Vincent, 2009).

In tropical regions, the ichthyofauna is more diverse and probably less resilient to climate change than temperate fauna because of a higher degree of adaptation to very specific or localized environmental conditions. This has resulted in less capacity to cope with environmental change, particularly with reference to modifications to longitudinal and lateral connectivity (Gough, *et al.*, 2012). Apart from the rise in temperatures and likely decreased oxygen levels, changes in flow regimes are a major concern. These are expected to result from shifts in precipitation and evaporation patterns. Changes in flow regimes can be particularly problematic to migratory species that depend on these flows as a cue for migration.

There are already many examples of climatic changes around the world. In southwest Australia. a 50% reduction in median stream flow has been reported since the 1970's, and this continues to have both direct and indirect impacts on freshwater fish populations (Beatty, et al., 2017). In Africa, river discharges are predicted to reduce substantially, particularly in drier areas in southern and northern Africa (Thieme, et al., 2010). This is of concern to potamodromous species such as the largemouth yellowfish (Labeobarbus kimberleyensis) which is endemic to the Orange-Vaal River system in South Africa. This fish has been shown to be sensitive to flow modifications and habitat availability (O'Brien, et al., 2013). Impacts are also expected to be exacerbated by increased frequency of extreme climatic events, such as floods and droughts. Building of dams to mitigate water shortages, increased need for water for agriculture, and flood abatement, will cause increased habitat fragmentation and will be another increasing threat from climate change.

Direct impacts on fish migration and spawning can stem from changes in timing, intensity and duration of flooding (FAO, 2010). For example, a young salmon can successfully migrate to sea only during a brief spring-time window during which it becomes physiologically adapted to saltwater from changes in water temperature and day length. If it arrives too early or too late, it is less likely to survive the transfer to saltwater.

Because of their great importance, fisheries and especially migratory fish must be included in the global climate policy dialogue. The reason for this is clear and is exemplified by the work of Allison, *et al.*, (2009), who report that around 520 million people around the world are dependent on river

SPECIES EXAMPLE

Fish steeplechase race: The Streaked Prochilodus (*Prochilodus lineatus*) in the Pilcomayo River: Bolivia

Authors: Organization:

Country:

Jaime Sarmiento & Soraya Barrera División de Peces. Museo Nacional de Historia Natural Bolivia



Life cycle

The Streaked Prochilodus (*Prochilodus lineatus*), locally known as sábalo or Curimbatá, is a potamodromous South American fish, widely distributed in the Paraguay-Paraná basin. In the Pilcomayo River the fish spawn during the rainy season within the sub Andean rivers of Southern Bolivia. After spawning, eggs passively drift down to the wetlands of northern Argentina and Paraguay, where the fish feed and grow. After two years, when they reach sexual maturity, the adult fish move to the main channel to complete the cycle.

Geographic distribution

P. lineatus is widely distributed throughout the river basin in Argentina, Bolivia, Brazil, Paraguay and Uruguay (Castro and Vari, 2004). Studies on population structure have revealed that throughout their range, there are high levels of genetic variation but a lack of population subdivision (Revaldaves *et al.*, 1997; Sivasundar *et al.*, 2001).

Human impacts

For centuries, Streaked Prochilodus has had a prominent role in the subsistence economy of the native people of the Pilcomayo River basin. However, whilst the species has been severely commercially exploited by artisanal fisheries since the second half of the last century, a critical population decline has only recently been seen.

Other factors influencing the current decline of fish populations are: mining pollution in the headwaters, river diversion and channeling for irrigation connected to expansion of agriculture, and deforestation which in turn contributes to increased levels of erosion and siltation.

High levels of siltation can cause blockages at the confluence with the Paraguay river that could have implications for survival of the stock due to disruption of genetic flow (Smolders *et al.*, 2002, Swinkels, 2012).

SOLUTIONS

Better understanding of fish stock dynamics is crucial in order to understand the current impact of natural and fishery mortalities. There is also a need to understand the risks of population isolation as a result of disruption of continuity with the Paraguay river.

Political decisions will strongly determine the success of population restoration. Management

of aquatic ecosystems and fish populations, requires a multinational approach between Argentina, Paraguay and Bolivia, both at national and subregional levels.

The Bolivian government recently approved national legislation on sustainable fisheries and aquaculture. Nevertheless, it is also necessary to fulfill regulations on specific issues, including the implementation of a good system for fishery records.

ARTISANAL FISHERIES

Fishing for Sábalo (Prochilodus lineatus) in the Pilcomayo River basin. © Cimar Farfán.



SÁBALO (PROCHILODUS LINEATUS) From the Pilcomayo River basin. © Soraya Barrera.



WHAT ARE THE KEY DRIVERS?

Local fisheries are sustained mainly through the catch of Sábalo. Despite being a seasonal activity, the fishery represents the main income for people in the town of Villamontes (Tarija, Bolivia), and people of the Weenhayek native group. Restrictions on fish size or seasonal fisheries closures, may result in increases in illegal catches of fish.

Increasing agricultural crop development in the Chaco lowlands is leading to an increasing demand for water, which in turn can contribute to an increasing isolation of fish populations of the Pilcomayo River. Abstraction of water has also been related in the past to fish mass mortality.

LOOK TO THE FUTURE

It will be necessary to:

- Implementation of an effective management plan for commercial Sábalo fisheries is essential. The process must involve regional and national stakeholders, fishermen, and indigenous peoples of Bolivia, Argentina and Paraguay;
- Increase our understanding of connectivity with the main Paraguay river and related genetic exchange;
- Establish a management plan for the hydrological resources of the Pilcomayo River;
- Reduce pollution, especially with heavy metals;
- Create awareness in the local population about the importance of the species as an essential element of the ecosystem and as a food resource for future generations.

Table 4.1

Countries with the highest number of dams around the world (International Commission on Large Dams, 2011). This is based on 58,519 dams data corresponding to registered dams only (July 2011).

	Countries with the highest number of dams	World Register of Dams	
1	China	23 842	
2	United States	9362	
3	India	5102	
4	Japan	3112	
5	Brazil	1411	
6	Korea (Rep. of)	1339	
7	Canada	1170	
8	South Africa	1114	
9	Spain	1063	
10	Turkey	972	
11	Iran	802	
12	France	712	
13	United Kingdom	596	
14	Mexico	571	
15	Australia	570	
16	Italy	542	
17	Germany	371	
18	Norway	335	
19	Albania	307	
20	Zimbabwe	254	
21	Romania	246	

and floodplain fisheries for their wellbeing. Onethird 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.

4.5 PHYSICAL BARRIERS

The most significant influences on natural instream flow are barrages, weirs, dams and sluices. These instream barriers are built for various purposes including water conservation during dry periods, navigation, hydropower, irrigation, water supply or to protect against flooding. For instance, in the Netherlands a high percentage of land is below sea level and as such, thousands of pumping stations and sluices are needed to maintain rivers in engineered channels to protect these regions from flooding. Elsewhere many hundreds of thousands of barriers of one kind or another threaten fish migration capacity around the globe.

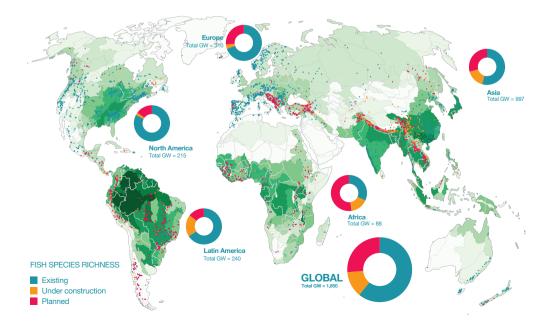
Large dams have gained much attention due to their inevitable impact on natural river environments, and the incompatibility between the services they provide to many human needs and their negative implications for ecosystem sustainability (Poff & Hart, 2002). Large dams are often promoted as instruments of development (World Commission on Dams, 2000), meeting perceived needs for water and energy services and serving as long-term investments to deliver multiple benefits. Table 4.1 shows the countries with the highest number of large dams. Promotion of industrialisation and associated job creation are also cited as additional benefits of dam developments. In recent years, there is a boom in dam building in developing countries in South America, Africa and Asia (Figure 4.3). The majority of the large dams constructed in these regions are focussed on hydroelectric generation however the political intent is for them to favour multipurpose functions including water supply and regulation of river flow. Other benefit claims have often been made, such as the development of commercial fisheries opportunity and aquaculture within the impounded body of water, however in the long-term these tend to be unfounded and unsustainable.

The growing need for electricity to meet consumer and productivity demands has increased the world's ambitions for large hydropower developments. This has resulted in sustained interest in large dam development, partly addressing increasing pressure for renewable energy sources. Currently renewables account for about 22% of global electricity production, and hydropower contributes about 16% of this (International Hydropower Association, 2015). According to Zarfl, *et al.* (2015), there are at least 3,700 dams, each with a capacity of 1MW (or more), either planned or under construction, primarily in developing areas of the world; largely in Asia, Africa and South America. The authors estimate that the hydropower projects currently in the planning stage will increase the present capacity by 73%.

The significant ecosystem impacts and issues of these developments have been raised by many. Dams are associated with transformation of natural hydrology, fish and wildlife habitats, the river continuum, local fish populations and the

Figure 4.3

Current, planned and under construction hydropower development of plants with a capacity of 1MW, or more as, represented within TNC Power of Rivers report (Opperman, et al., 2015). This map also highlights the fish species richness that is potentially influenced by hydropower around the world. Map courtesy of The Nature Conservancy.



EXAMPLE

Bringing back the Richmond River - the removal of Norco and Manyweathers Weirs

Authors: Organisation:

Country:

Matthew Gordos & Patrick Dwyer New South Wales Department of Primary Industries - Fisheries Australia



INTRODUCTION

Norco and Manyweathers Weirs were the highest priority barriers for remediation in the Richmond River catchment in northern New South Wales, Australia. Located just upstream of the tidal limit, these weirs blocked fish passage for up to 17 species of migrating fish for over 95 % of all flows. Constructed in the 1960s for water supply, they became redundant for that purpose by the early 2000s. However, sections of the community in the regional town where the weirs were located still valued them for recreation, visual amenity, and for platypus habitat.

TO BE REMOVED

The start of the removal of Manyweather weir.



WHAT DID YOU DO?

Environmental impact of weir removal was assessed as minimal as the low level weirs had been constructed on bedrock with negligible upstream sedimentation. However, the community raised concerns about potential deleterious impacts on platypus (*Ornithorhynchus anatinus*), a unique Australian monotreme but not a threatened species. A Platypus Risk Assessment was completed for the Manyweathers Weir removal which determined that although localized impacts were expected, platypus numbers in the region were healthy and would be sustained despite weir removal.

Heritage status was attributed to both weirs due to local aesthetics and representative design significance. In particular, Manyweathers Weir, prominently located in the township and owned by the state government, was named after the town's longest serving mayor. Consultation with the local and state heritage offices, as well as the Manyweathers family, resulted in an agreement to save a portion of the weir which was placed at the top of the bank with a plaque to commemorate the heritage.

A simple cost-benefit analysis was completed for Manyweathers Weir. Repair of existing breaches was estimated at \$100,000, with an additional \$360,000 required to construct a fishway to meet legislative requirements of the *NSW Fisheries Management Act 1994*. Alternatively, removal of the obsolete weir was estimated at \$80,000 with no further ongoing maintenance or liability requirements.

HOW DID IT WORK OUT?

Norco Weir was removed in 2007 as a component of a pipeline river crossing project immediately downstream. These works took three months to complete and a drop board structure in the weir helped manage flows at the worksite and enabled progressive lowering of the weir pool to reduce the risk of upstream bank slumping. Manyweathers Weir was removed two years later in 2009 over a much quicker five days; with the presence of bedrock-lined banks reducing the risk of river bed and bank erosion. No deleterious impacts have been noted as a result of weir removal.

LESSONS LEARNED

Consultation with the community about the weir removal projects was most effective when visual information about the expected outcome was presented at the start of the consultation

NORCO WEIR

This stone from the Norco weir is preserved for heritage significance.



process. A key aid for discussing community concerns for the Manyweathers Weir removal was a detailed survey of the entire weir pool which showed the location, extent, and depth of each pool and riffle zone that would remain during low flows following weir removal. This survey allowed the community to visualize what the river would look like post weir removal, and negated concerns that weir removal would leave behind a dry river bed.



REMOVAL OF NORCO WEIR

up and downstream migration of fish. In a recent review Winemiller, *et al.* (2016), the financial implications of hydropower development are highlighted. The authors raised the concern that economic benefits are overestimated, as economic projections often exclude or underestimate the loss of ecosystem services and the associated cost of environmental mitigation and the long-term maintenance or lifespan of hydroelectric projects.

For the three largest river basins in the world, the Amazon, Congo and Mekong, the longterm ripple effects of dam developments, acting cumulatively in each basin, on biodiversity and critically important fisheries are significantly underestimated. It may be that mitigating the scale of the impending damage will not be possible.

In many countries, the most common problem for fish migration is low head weirs (0.5 m - 4.0 m). Weirs have been constructed in a variety of ways, with local preferences in construction styles. Most have a fixed and level crest together with water control structures such as sluices and extraction 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 extraction (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. In Europe there are over a million dams and weirs estimated to be blocking free-flowing rivers (Garcia de Leaniz, 2016).

4.5.1 Impacts of dams on fish migration

There is a plethora of literature available on the profound consequences of hydropower and other instream barriers to migratory fish. In summary, longitudinal barriers 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 up and downstream migration. Pumping and hydropower stations can cause severe damage to downstream migrating fish that become entrained and impinged against screens and racks, or amputated as they 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 detailed knowledge of the size, shape, and 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 (head height). Some fish, notably salmon, may be able to leap small obstructions (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. Passage objectives should not be met through the results of exceptional swimming, leaping and crawling performance of some individual species;
- If a fish pass is present, the entrances are often too 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. Fish passes must be designed with ecological insights to attraction and swimming capabilities of each relevant fish species throughout their migratory season and a diversity of flow conditions. Optimum flows must be derived, and engineering solutions implemented to accommodate these;

- Deep ponded sections of river upstream. These are unlikely to represent functional habitat for the migrating species, often delaying migration, increasing opportunities for predation and conditions for oxygen or temperature barriers;
- Strong and turbulent flows downstream. In extreme conditions these 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. It is important that water is allocated to this;

 Altered temperature regime below the obstruction particularly with deep impoundments where warm water stratifies at the top such that excessive top release of water, warms downstream reaches and excessive bottom releases could be much colder than downstream reaches.

The mechanisms of impact of barriers on fish migration depend on the swimming ability and behaviour of the fish species. 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.

Damaged fish

Pumping stations can be damaging to migratory fish. This photo was taken at a pumping station near Ghent, Belgium. © Herman Wanningen.



BARRIERS EXAMPLES OF FISH MIGRATION BARRIERS WORLDWIDE

da da per



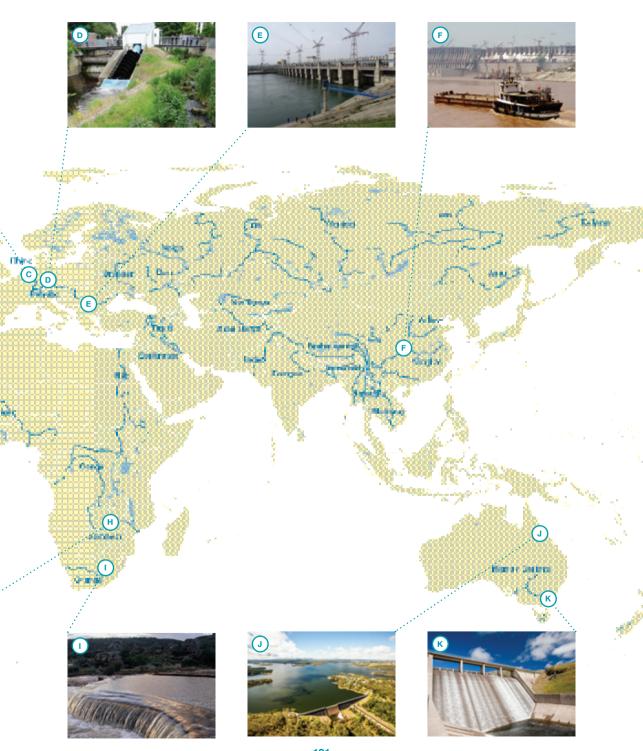




- A Small dam on Little Butte Creek, the dam provided water for a flour mill built in 1860, Oregon, USA.
 © Jamie Pittock/WWF.
- B H. Neely Henry Dam in the Coosa river, Alabama, USA © Kevin Schafer/WWF.
- C Tidal locks of the Cleveringsluizen, a tidal barrier between the Wadden Sea and Lake Lauwersmeer (The Netherlands). © Herman Wanningen.
- D Archimedean screw hydropower station bypassed with a fishway in the Bocholter Aa, Germany. © Wilco de Bruijne.
- E The Iron Gate Dam II in the Danube on the Romanian-Serbian border. © Wilco de Bruijne.
- F Construction of the Three Gorges dam on the Yangtze River, the world's largest hydro power station. Hubei Province, China. © Michel Gunther/WWF.
- G Itaipu dam in the Paraná River between Brazil and Paraguay. This dam is equiped with a fish passage facility. © Michel Gunther/WWF.
- H Hartebeesport dam, built to provide water for irrigation, domestic and industrial use, South Africa. © Martin Harvey/WWF.
- I Water management in South Africa, most rivers are dammed or at least weired © Chris Marais/WWF.
- J The Tinaroo Falls dam, Queensland, Australia. © James Morgan/WWF.
- K Gathega Dam supplying the water to Guthega power station, New South Wales, Australia. © WWF.







Lateral migration

Lateral fish migration in some rivers is severely constrained by dykes, levees, roads and flood banks. These structures can isolate rivers from potential wetlands and floodplains in the river vallev 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 can also lead to isolation of the river from riparian habitats or prevent the establishment of such habitats as rivers natural evolve or shift course. In addition to these direct impacts there are also indirect impacts caused by downstream regulation that influences water flow and sediment deposition rates onto floodplains (Timberlake, 2000). In the Zambezi River floodplains are a key habitat for about 31 fish species associated with lateral migration, however the erratic flow regulation resulting from the operation of the Cahora Bassa dam in the 2000's were predicted to alter flows sufficiently to negatively impact fish migrations into the floodplains.

Downstream migration

In the great majority of rivers with weirs or dams, there are water intake facilities and these have often trap, damaged or kill downstream migratory fish. The nature and degree of damage varies substantially depending on the number and types of water intake, the proportion of flow abstracted at each and the presence of effective bypasses and truly protective screens. Large scale mortality of downstream migrating fish has severe ecological consequences for the fish stock as these losses may compound with densitydependent factors after immediate mortality at the dams they passed. For species such as salmon, compensation through re-stocking has been used, however this has recently been recognised as undesirable because of genetic risk to the recipient population. For some species such as eel it is possible to compensate for damage by restocking, however the availability of juveniles (elvers) is increasingly uncertain as the annual catch of fish varies widely. The loss through entrainment of commercially important species will increasingly have negative economic consequences due to the loss of recreational and commercial fishing opportunity.

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

- Hydroelectric power plants: At some hydroelectric power plants, damage to fish can occur as they pass through turbines, even when protection through the use of screening combined with bypasses and guidance systems is in place. Damage by passage through turbines often varies from 5 to 40%, but can in some circumstances (for example with long-bodied fish like eel) be much higher and up to 100%. Adequate flow must be allocated to bypass systems to both attract fish and minimize damage;
- Pumping stations: Pumping stations are often used in lowland areas throughout the world for the purpose of water management to maintain water levels and reduce the risk of flooding. Damage to fish through entrainment or impingement on racks in front of turbines or during passage through pumps is comparable with that in hydroelectric power plants;
- Industrial and potable water intakes: In many river systems water is used for industrial purposes, including cooling, and for potable supply. In some cases these extractions 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 principal flow line in their migration and can therefore be led into an intake, where they are exposed to the risk of injury and mortality. Even if not injured this could lead to fish being unable or unwilling to return to their migration;
- Mechanical barriers: Racks or screens are used to prevent trash or debris entering water intake facilities used for industrial water supply, for turbines and pumping stations. Damage

can occur due to impingement of fish as a consequence of high and sustained flow velocities towards the rack or screen. According to (Beamish, 1978) many fish can overcome flow velocities of just around 0,5 m/s, but only if they are motivated to do so;

- Large drops over weirs and spillways: 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*: Deteriorations in water quality in the area of physical barriers can influence both up and downstream migration (Section 4.2).

4.5.2 Impact of dams on river ecosystems *Fragmentation*

The degree to which river systems are impacted by instream barriers worldwide can he demonstrated by analysis of flow regulation to determine the degree of fragmentation. Recently, Grill, et al. (2015) calculated the accumulative impact of over 9,000 existing and planned large dams on river fragmentation and flow regulation. The results showed that 48% of global river volume is moderately to severely impacted by flow regulation and/or fragmentation. This would nearly double to 98% if all planned dams and those under construction dams were also considered, specifically those in the Amazon region where there is a large programme of dam construction. Updating the work from from Nilsson et al., (2000: 2005), a total of 1,293 large river basins contains large dams and an additional 200 basins will be affected by future dams. Although the percentage of rivers that are unaffected by large dams is about 41%, many of these dams are in arid or semi-arid regions. If river volume is considered, then only 7% of the world's river volume is within basins unaffected by large dams.

Flow regulation

Flow regulation is one of the main adverse ecological consequences of dams and reservoirs to rivers. This is evident in downstream river ecosystems and is a result of dam operations reducing natural flows, eliminating peak flows, changing seasonal flow patterns, regulating low flows or other regulatory practices. The problem is that many fish species have adapted to specific flow patterns in certain seasons and developed a dependency on certain flow related cues to reproduce, migrate, feed and survive. In order to mitigate these issues, many governments worldwide have directed dam operations toward releasing certain "environmental flows". These flows are set at the minimum required quantity, quality and timing of water flows required to sustain ecosystems and human activity and livelihoods. There are a vast number of methodologies used to evaluate environmental flow requirements, most of which have been developed in USA, Australia, UK, Canada, South Africa and New Zealand (Tharme, 2003).

Habitat and ecology

Larger structures such as large barrages and dams inevitably lead to stream channel changes due to the alteration of flow, and often with a loss of diversity in flow patterns decreasing from source to sea.

Downstream of every barrier there is a short zone with relatively high velocities and turbulence. Both tend to decrease the further you go downstream and with additional inputs from tributary streams, a more natural hydrologic regime can be re-established, provided another barrier isn't encountered. 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 as sediments are deposited behind

EXAMPLE

Environmental Flows, minimum flows and the mystery of ten percent

Authors: Organisation:

Country:

Jackie King^{1,2} & Cate Brown^{1,3} ¹Institute for Water Studies, University of the Western Cape; ²Water Matters & ³Southern Waters South Africa



INTRODUCTION

Humanity has benefitted in many ways from water-resource developments such as dams, but unexpected costs have appeared. Land loss and displacement of people associated with a new reservoir were immediate impacts, but interruption of the upstream-downstream linkages of water, sediments and biota has proved the most pervasive cost. It has the potential to negatively affect the diversity and resilience of whole river systems, crossing regional and national boundaries and with knock-on effects into politics and human conflict. Recognising this, a new discipline, often called Environmental Flow Assessments, has emerged to provide ecological and social information on water management plans for use in negotiation, stakeholder engagement and decision making (King *et al.*, 2014).

THE OKAVANGO DELTA, BOTSWANA

A comprehensive EFlows Assessment of the Okavango Basin (Angola, Namibia, Botswana) in 2008, led by the authors, provided water-resource scenarios of possible futures now being used by the three governments in basin development planning. © J. King.



TABLE 1

Analysis of data from Figure 1, to show the natural onset and duration of the wet and dry season and the modifications brought about by a minimum flow release plus spills: the dry season starts earlier and is almost twice as long; the wet season starts later and its duration is reduced by two-thirds. EFlows Assessments interpret these predicted hydrological changes in terms of the impacts on fish communities, other ecological components of the river and dependent social structures.

Season indicator	Units	Natural flow regime	'Minimum flow', plus spills
Dry season onset	Calendar week	37	28
Dry season duration	Days	143	236
Wet season onset	Calendar week	10	14
Wet season duration	Days	166	50

ENVIRONMENTAL FLOWS

The flows negotiated for river maintenance are called Environmental Flows (EFlows).¹ Setting them is now a recognized and obligatory part of most major water-resource developments, but the way they are set differs widely between projects and regions. In their most detailed form they provide scenarios of different potential economic, ecological and social costs and benefits, influencing the way that dams are designed and operated and where they are located. There is now an emerging trend, however, to sometimes simplify the assessment and minimise the EFlow specifications to the point where EFlows themselves are in danger of becoming a symbolic gesture - a box to be ticked.

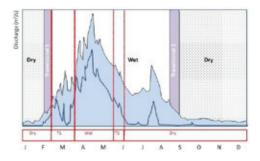
MINIMUM FLOWS

One of the driving forces behind this is promotion of a concept that the impacts of dams on the upstream-downstream river linkages can be adequately mitigated through the provision of a minimum flow downstream of the dam. This may be specified as a single number, sometimes just for the dry season but possibly for the whole year. The convenience of such a single number for

1 Brisbane Declaration, 2007: EFlows are the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. planning and design purposes is understandable, but there is no evidence that such a flow will support natural aquatic ecosystem functioning. Indeed, the body of evidence indicates the opposite. Dry and wet season low flows, small and major floods, and natural periods of low/no flow all play a role in maintaining the river ecosystem, and changes in any of these will change the nature of the river. Reservoirs that spill in the wet season

FIGURE 1

Based on long-term natural flow data for a specific point along a specific river, and using the DRIFT-Hydro software, the year was divided into four flow seasons: Dry, Transitional 1, Wet and Transitional 2. In scenarios including future dams, the hydrograph of natural flows (blue shaded area) would be modified and reduced downstream to provide minimum flow releases and spills (lower line). This would alter the onset and duration of the flow seasons to those shown by the red divisions.



>>EXAMPLE

may help retain some seasonal variability in downstream flows but they still substantially alter the onset and duration of the different seasons (Figure 1 and Table 1). To address this, an EFlows specification should describe the magnitude, timing, frequency, duration and rate of change of each of the flow components.

THE TEN PERCENT RULE

Equally concerning is calculation of the singlenumber minimum flow as 10% of some flow metric, with an astonishing lack of consistency in the metric used. It has been calculated as 10% of Average Annual Flow (AAF) (Figure 2), 10% of minimum flow, 10% of dry season flow and,

FIGURE 2

Hydrograph of eight years of natural flows, showing the 10% of Average Annual Flow, which is often allocated as an EFlow.

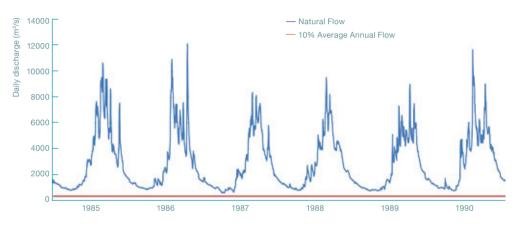
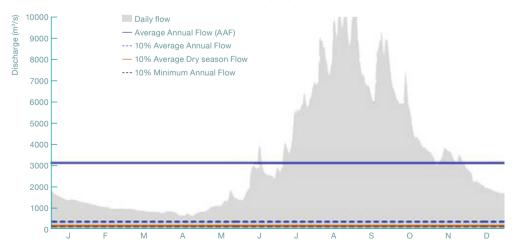


FIGURE 3

An annual hydrograph of daily flows, with various single-number minimum flows, illustrating the loss of magnitude, seasonality and variability of flow that they represent.



NEELUM RIVER, PAKISTAN

The authors and local water managers share knowledge of the Neelum River, Kashmir, Pakistan. A comprehensive EFlows Assessment of the impact of the proposed Kishenganga Dam in India on the downstream river in Pakistan was done in 2011. The results were used by the Permanent Court of Arbitration in The Hague to award a specific downstream flow that must be released to Pakistan. © H. Beuster.



worse, 10% of 'available' flow or 10% of 'residual' flow. Each of these produces a different minimum flow specification, usually lower than any that occurred naturally thus pushing the river into permanent drought conditions (Figure 3). Despite this, the 10% allocation, in its various forms, has been described in such terms as 'consistent with national requirements', a 'default legal/ government requirement', a 'generally applied hydrological method', 'informal government policy' and 'accepted practice' (internal government, donor and consultancy documents).

Leading EFlows practitioners write that despite the widespread use of the 10% approach, they have no idea of its origin, and scientific justification in terms of the ecosystem services that it will support has not been found. One possible origin is the 10% of AAF said by Tennant (1976) to support poor fish habitat and poor overall river condition - a management objective not conducive to sustainable development. Another possible origin is the 'attraction flow' at a fishway entrance, which is sometimes designed as 10% of some flow metric or some other fishway metric (e.g. NMFS 2008). Perhaps the 10% 'attraction flow' came to be seen as sufficient for the fishway and thus also for maintenance of the downstream river. Whatever its origin, the specialists concur that while a 10% allocation is not automatically incorrect, the 10% rule is not an EFlows Assessment as it bypasses examination of the whole hydrograph and of the importance of different flows for ecosystems and people. It also avoids development of scenarios for stakeholder consultation, thus by-

>>EXAMPLE

passing IWRM (Integrated Water Resources Management) requirements for meaningful stakeholder engagement.

In summary, the 10% approach:

- is simple and quick;
- allows an upfront proportion of flow to be allocated "to the environment" in hydrological models;
- is a very low 'swallowable' amount to allocate to the environment;
- is used inconsistently, possibly without understanding the implications.
- in terms of ecosystem support, may do more harm than good because it may give stakeholders the impression that the environment has been "taken care of"

• remains poorly justified - there is no obvious scientific evidence of what it will achieve.

CONCLUSION

EFlows Assessments evolved to help us understand, predict and potentially mitigate the negative impacts of dams and other waterresource developments. It is short-sighted and careless for water-resource planners, developers and funders to bypass a formal EFlows process, as this would contribute to more informed and equitable decision making. EFlows Assessments also increase awareness and understanding of the underlying functioning of river systems and of the many natural resources they provide in addition to water. The livelihoods of millions of people globally depend on these natural resources.

THE MATSOKU RIVER, LESOTHO

The Matsoku River, one of the rivers involved in the Lesotho Highlands Water Project, southern Africa. A comprehensive EFlows Assessment in 1997 led to EFlow regimes being installed downstream of the dams to sustain the rivers and local livelihoods. © J. King.



Importance of preserving riverine fisheries

A) Young boy holding the migratory small scale mud carp (Cirrhinus microlepis). © Zeb Hogan. B) Traditional fisheries for Inle carp with cast nets on Inle lake and its tributary streams, Nyaung Schwe, Myanmar. © Wilco de Bruijne. C) Large catfishes caught in Rio Negro, main protein source in the Amazon river basin. Manaus fish market, Amazonia, Brazil. © Michel Roggo/WWF.







stream barriers. This is also dependant 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 free-flowing stretches in a dammed river, depend strongly on the number of structures and the degree of impoundment.

These habitat modifications can profoundly affect 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 otherwise not be found. Reservoirs can transform faunal composition into communities of species characteristic to that of a lake. The natural estuary of a river is a vitally important transition zone. A gradual transition of salt concentration and temperature gives diadromous 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 stress to migrating fish that might be poorly prepared for rapid transition between the two 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, has a large impact on local biodiversity.

Consequences to riverine fisheries

Dams have generally resulted in negative impacts on riverine fish and fisheries throughout the world (Jackson & Marmulla, 2001). The loss in fish yield can sometimes be partly compensated by new fisheries in some large reservoirs, however this does not generally maintain biodiversity value and may only be a temporary benefit. The fish yield in floodplain river ecosystems is directly related to the height and duration of floods. Dams that reduce downstream inundation of floodplains will therefore have a negative impact on overall fisheries production. Fisheries dependant on migratory fish are generally severely impacted by dams. In many cases, 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 there is still incremental, and sometimes substantial loss of fish passage at each.

Barriers can also result in the isolation of subpopulations of fish stocks. For species that are not able to fulfil their lifecycle, for instance diadromous species, this can have major consequences for stock survival. Decline of habitat quality can also detrimentally affect nonanadromous populations, causing a bottleneck for dispersion to larger networks of more and more diverse habitats. Fragmentation can result in ecological and behavioural changes, physiological problems, genetic degradation and deterioration of habitat structure of rivers.

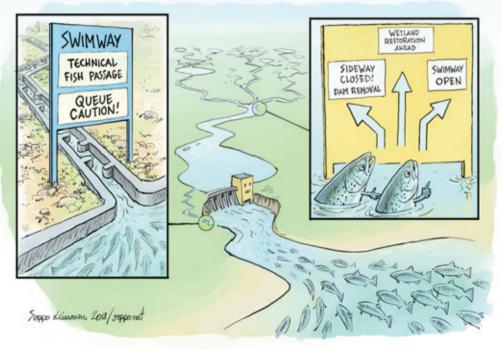
CHAPTER 5 RIVER BASIN APPROACH

Ruiten Aa River, The Netherlands. © Herman Wanningen.

INTRO

Many rivers throughout the world have been heavily modified by human activities and this has invariably led to large decreases in ecological quality. Increasingly work is being carried out to restore river habitats and fish migration, but in many cases this is limited by financial resources or social and technical constraints. Goals for restoring fish migration should be planned carefully, preferably within the context of an entire river basin, taking into account of the available habitat and potential scope for upstream and downstream migration within the river continuum.

SWIMWAY UNDER CONSTRUCTION



5.1. RIVER BASIN MANAGEMENT OVERVIEW

With the rising threats to rivers and their biota around the world, there is an increasing need to manage river ecosystems sustainably and in an integrated manner. We need to consider the full suite of ecosystem services for both human and natural needs, but also integrate policy. institutional, economic, social, environmental and legal issues into these plans (Gough, et al., 2012). In 2000, the IUCN considered each of these aspects in the development of the 'River Basin Approach', which is an ecosystem and social strategy for basin management. This approach is now established in the Ramsar Convention on Wetlands and has become an important and fundamental part of global water management activities. It also forms the scientific and societal basis for many river management programmes around the world.

The River Basin Approach is a key element in the process of finding equitable solutions for resolution of hazards and obstacles to migratory fish in a whole river context. It is also helpful for considering associated elements of policy and legislation, maintenance, evaluation of fishway facilities and communication, education and financial issues.

This River Basin Approach is also recognized within the Swimway approach (Section1.3) that adopts these well-established methodologies. This is used as a successful management approach to setting solutions for migratory fish in catchments.

5.2 RIVER BASIN MANAGEMENT PLANS AND PRACTICES

River basin management plans are developed to provide an overview of the conditions, problems, objectives and measures in a water management or watershed system. They incorporate the River Basin Approach, which assimilates the many issues that influence the services and functions provided by a watershed and integrates this across scales, sectors and communities. Not only do these plans assess the whole catchment, they also include action plans to set strategic objectives (including target fish species and ecological targets) and to identify and prioritize barriers to fish migration including those that cross national boundaries.

Garrick provides a good review of the governance of large river basins around the world (Garrick, *et al.*, 2014). Some 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.

There are many other river basin plans around the world that have been successful. In Spain river basin management plans have resulted in the planning for over 100 dam removals (Brufao, 2008). In the USA, numerous programs have had a significant role in restoring fish populations and their habitats such as the USFWS Salmon of the West program, USFWS National Fish Passage Program, National Fish Habitat Action Plan (NFHAP), the completed Penobscot River Restoration Project in Maine and the planned Klamath River Restoration Project in California.

USFWS Salmon of the West program

This program has supported over 30 on-theground habitat restoration projects protecting and conserving aquatic, estuarine, wetland and associated terrestrial habitats, and practices for 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.

USFWS 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 USFWS in 1999, the NFPP is a voluntary, non-regulatory initiative that provides 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

EXAMPLE

Prioritizing barriers in the Chesapeake Bay watershed

Author: Organisation: Country: Erik Martin The Nature Conservancy United States of America



INTRODUCTION

The anthropogenic fragmentation of river habitats through dams and poorly designed culverts is one of the primary threats to aquatic species in the United States (Collier *et al.*, 1997; Graf, 1999). The impact of fragmentation on aquatic species generally involves loss of access to quality habitat for one or more life stages of a species. For example, dams and impassable culverts limit the ability of anadromous fish species to reach preferred spawning habitats and prevent brook trout populations from reaching thermal refuges. There is growing momentum in the eastern United States to remove old dams, many of which no longer serve their intended purpose. However, limited resources dictate that potential dam removals or other fish passage projects be prioritized so that scarce funds can be applied where they can have the greatest ecological benefit.

WHAT DID YOU DO?

Working with the multi-stakeholder Chesapeake Fish Passage Workgroup, The Nature Conservancy developed a prioritization of dams in the Chesapeake Bay watershed in the states of Maryland, Virginia, and Pennsylvania (Martin and Apse, 2013). This work follows the same conceptual approach as similar projects in the Northeast U.S. (Martin and Levine, 2017) and Southeast U.S. (Martin *et al.*, 2014). This approach includes steps to:

SIMKINS DAM REMOVAL

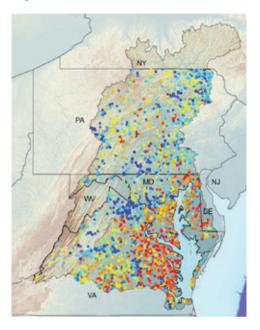
Before and after the removal of the Simkins Dams on the Patapsco River in Maryland, United States. © Mary Andrews / NOAA.





FIGURE 1

Dams in the Maryland, Virginia and Pennsylvania portions of the Chesapeake Bay watershed. Warm colors are higher priorities for improved passage for diadromous fish including river herring and shad.



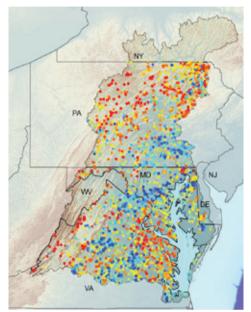
- 1 Develop a comprehensive database of dams in the study area;
- 2 calculate a suite of ecologically-relevant metrics for each dam;
- 3 subset and weight the metrics to develop prioritizations that reflect one or more restoration objectives (e.g. diadromous or resident fish populations);
- 4 develop a custom analysis tool to allow users to develop their own prioritizations that reflect their objectives (e.g. for a specific species or within a specific sub-geography).

HOW DID IT WORK OUT?

The results of this project have been used by the Chesapeake Bay watershed river restoration community to help identify potential dam removal projects, support project funding requests,

FIGURE 2

Dams in the Maryland, Virginia and Pennsylvania portions of the Chesapeake Bay watershed. Warm colors are higher priorities for improved passage for resident fish species, such as brook trout.



and support outreach and communication efforts for ongoing dam removals. They have also been used by funders to provide a screeninglevel assessment of proposed dam removals and to help inform funding decisions. Finally, the project database has been used to provide metrics and measures for tracking river restoration progress over time.

LESSONS LEARNED

While regional-scale prioritizations cannot capture much of the site-specific information that can make-or-break a proposed dam removal, such as local support or opposition of a project, they nonetheless can provide a valuable framework for assessing the potential of a given connectivity restoration project to benefit target species.

EXAMPLE

Watershed scale conservation of westslope cutthroat trout

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



INTRODUCTION

Westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) were historically the most abundant and broadly distributed of the cutthroat trout taxa in western North America (Behnke, 1992). Today, this species is found in less than 10% of its range due to loss of habitat and competition and hybridization with introduced trout species (Shepard *et al.*, 2005). Conservation management actions for westslope cutthroat trout aim to protect and expand populations of this native fish that serves an integral ecological role in aquatic systems and is important socially and economically as a sport fish.

The South Fork Flathead River drainage (2,705 km²) comprises approximately half of the remaining interconnected habitat for nonhybridized migratory forms of westslope cutthroat trout and is considered a stronghold for this species. Although wilderness designation of these lands in 1964 has largely protected this watershed from anthropogenic habitat degradation, historic stocking of nonnative 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 westslope cutthroat in the South Fork Flathead drainage.

WHAT DID WE DO?

In 2007, Montana Fish, Wildlife & Parks, the

United States Forest Service, and Bonneville Power Administration began implementation of a watershed scale conservation program with the goal of eradicating non-native trout from 21 headwater sources and re-establishing populations of westslope cutthroat. This species exhibits substantial genetic divergence among populations, even over small geographic scales (Allendorf and Leary, 1988). Therefore, conservation of genetic variation requires ensuring the continued existence of many populations across the species' range. To achieve this goal, multiple genetically distinct westslope cutthroat populations have been used as donor stocks to reintroduce this species to waters after non-native trout have been removed.

WESTSLOPE CUTTHROAT TROUT © Matt Boyer.



HOW DID IT WORK OUT?

Piscicide eradication of headwater sources of non-native trout was completed in 2017 and naturally reproducing populations of westslope cutthroat have been established in secure headwater lakes and streams. These habitats provide cold water refugia for this species and additional buffering capacity against increasing water temperature that is predicted to occur with climate change. Additionally, the use of local genetic strains of westslope cutthroat enhances the ability of populations to adapt to changing environmental conditions and promotes long-term species persistence. This approach represents a substantial advancement in the conservation of genetic variation in native fishes with a high degree of interpopulation divergence.

LESSONS LEARNED

Public involvement and outreach are essential to the success of native fish conservation programs. Additionally, extensive monitoring of amphibian, zooplankton, and aquatic macroinvertebrate communities has shown that the piscicide rotenone was effectively used for native trout restoration with only minimal and short-term effects on nontarget species. Success achieved with this project will promote westslope cutthroat conservation efforts elsewhere within this species' range.

KOESSLER LAKE, BOB MARSHALL WILDERNESS, MONTANA © Matt Boyer.



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 reopened 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 USA 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 US 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 USA have been assessed and a Status of Fish Habitats in the USA report was released in 2010 (National Fish Habitat Board, 2010). Furthermore over 12 Fish Habitat Partnerships in priority areas have been established and projects to protect, restore, and enhance priority habitats are funded.

European Water Framework Directive

The EU Water Framework Directive requires that every member state produces and implements River Basin Management Plans and abides by the delivery objectives. In 2009 each of the member states were obliged to submit descriptions and implementation plans to reach "Good Ecological Status" objectives (Section 6.3.3). Much effort has since gone into preparation of the initial River Basin Management Plans and these now present a much better understanding of the status of water resources. However, more effort still needs to be done to ensure the achievement of the Water Framework Directive objectives in 2021 and 2027.

5.3 INTEGRATED CATCHMENT MANAGMENT

Integrated catchment management is a critical matter as more countries consider re-aligning local management on political rather than river catchment boundaries. Integrated catchment policy and planning has not been universally adopted and basin management is complicated by factors such as:

- · Limited government budget allocations;
- Poorly informed and advised decision makers and managers;
- Weak policy, legal and institutional frameworks that do not provide for integrated management of water resources;
- The presence of international water bodies that complicate the management of water resources;
- The cost and benefits of ecosystems are not considered or prioritized;
- The capacity or resources to assess the current status of catchments is limited;
- The capacity to manage, monitor and enforce regulations is inadequate;
- Communication and representation of stakeholders within the decision-making and management processes is not in always place;
- Large corporations and financial institutions may have a large influence over local authorities who may lack the insights or capacity to ensure protection of local ecological and cultural resources.

There are many examples of poor water resource management impacting ecosystems as well as influencing the GDP of a country. For instance, in Kenya, inadequate water resource management resulted in several issues including poor water allocation decisions based on inadequate hydrological information. This contributed to a range of related problems including: over exploitation of groundwater resources resulting in a lower water table, deterioration in water quality due to uncontrolled discharges of urban and industrial waste, reduced fish production resulting from eutrophication, impacts on aquatic ecosystems from the invasive water hyacinth and chronic sedimentation within large dams. The accumulation of these and related issues over many years were estimated in a World Bank report to have a significant negative impact on the Kenyan economy (Mogaka, et al., 2006).

River management plans in developing countries are crucial for the future of healthy fish stocks. There are many lessons to be learnt from Australia, North America and Europe where currently fish passage policies are being implemented (Herman Wanningen, 2018, pers. comms.).

In addition to the complexity of issues that must be considered within the integrated catchment approach, there is also the issue of supracatchment management in many places.

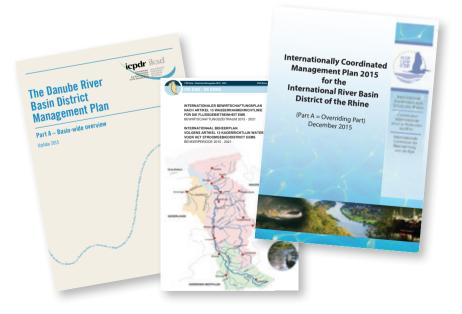
A study by Hoekstra (2011), suggested that even basin level management is no longer sufficient in a world with a growing number of inter-basin water transfer projects, the growing importance of multinational corporations that own dams in many jurisdictions and watersheds, climate change issues and the effect of global economies on water usage.

5.4 RIVER BASIN ORGANISATIONS

Some integrated river basin organisations have been in place since the 1930's. From a historical perspective, development-oriented basin organisations probably reached their zenith in the 1940's-1970's dam building era, when the 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 organisations, 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 organisations or national water agencies and international water organisations, and the more proactive of them continually 'retool' their business towards a broader mandate of social and ecological sustainability (Hooper, 2006).

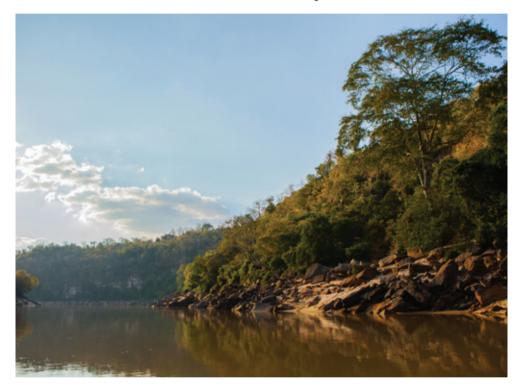
Management plans

Examples of the river basin approach, management plans for the rivers Danube, Ems and Rhine. In Europe all rivers have their own River Basin Management Plan, written in the context of the European Water Framework Directive.



Dam issues inf Tanzania

Stiegler's Gorge on the Rufiji River in Selous Game Reserve, Tanzania. In 2014, Selous was put on the UNESCO list of World Heritage in Danger, mainly due to increased poaching that resulted in a dramatic decline in wildlife populations. There are also industrial threats from mining explorations and planned hydropower dams. For more than a decade a proposal was put forward by Rufiji River Basin Authority (RUBADA) to build a hydropower dam within the gorge. WWF in collaboration with the Tanzanian government, Frankfurt Zoological Society and other partners, is working to create a sustainable future for Selous Game Reserve that will maintain its natural value. © Greg Armfield/WWF.



In many cases river basin organisations have been designed to help bring about integrated water resources management and improve water governance in trans-boundary water basins. All evidence suggests that these organisations are becoming increasingly significant in every region of the world. Throughout history, inter-nationally shared rivers were managed through treaties. The International Network of Basin Organisations currently has 134 member organisations in 51 countries, not including the river basin organisations at local and state levels. These enable governments

that share rivers to come together to coordinate activities, share information, and develop integrated management approaches. (For an overview of river basin organisations around the world see: www.transboundarywaters.orst.edu.

5.4.1 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

KEY CHINESE ACTION PLANS AND MANAGEMENT PROGRAMMES

Kerry Brink (World Fish Migration Foundation, The Netherlands), Luhong Wang (The Nature Conservancy, China), & Hui Zhang ((The Nature Conservancy, China)

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

The Chinese government published the China Biodiversity Protection and Action Plan requiring "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 in the Lower Jinsha may well destroy the last remaining habitat for many rare fish species on the Upper Yangtze and cause their extinction (Liu, 2011).

The Yangtze River Conservation

In recent years, the Chinese Government has paid more and more attention to the protection of ecological environment of the Yangtze River. In 2016, President Xi Jinping suggested to the government that there should be increased emphasis on conservation of the Yangtze rather than development. In July 2017, the Government issued the 'Ecological Conservation Planning of the Yangtze Economic Belt' intended to restore fish habitats in the Yangtze River through construction of fish passage and restoring fish habitats for rare and endemic species (Luhong Wang, 2017 Pers. Comms.). Furthermore, in November 2017, the Ministry of Agriculture issued a regulation that prohibits fishing in 332 fish conservation areas in the Yangtze Basin that will take effect in January 2018 to allow fish population to recover.

China's Water Ten Plan

Water Pollution Prevention and Control Action Plan was initiated in 2015. This plan is the coordination of 12 ministries and government departments with the aim of controlling pollution issues, strengthening management and water environment safety and clarifying responsibilities and engaging with public. It also promotes science and progress (China Water Risk, 2015). There are 238 specific actions with the focus toward key rivers noted as Yangtze, Yellow, Pearl, Songhua, Hai and Liao River.

EU-China River Basin Management Programme and CEWP

In 2006 the EU and China initiated a program to establish integrated river basin management practices in the Yellow and Yangtze River basins drawing on European expertise. The program significantly contributed to the converging of the Chinese and EU approaches to integrated river basin management (IRBM). In the Yangtze River basin the combined efforts has worked to enable greater stakeholder consultation and participation. This program was closed in 2012 and resulted in the establishment of the China Europe Water Platform (CEWP). The CEWP is meant to continue policy dialogue between China and Europe (www.cewp.eu).

(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 of the relevant agencies operating nationally, and those involved within the river basin itself as well as local communities (Ramsar Convention Secretariat, 2007).

EXAMPLE

The importance of having a good database for restoring river connectivity: the AMBER Barrier Atlas in Europe

Authors:

Carlos Garcia de Leaniz¹, Barbara Belletti², Simone Bizzi², Gilles Segura³, Luca Börger¹, Joshua Jones¹, Rosa Olivo del Amo⁴, Herman Wanningen⁴, Jeroen Tummers⁵, Jim Kerr⁶, Paul Kemp⁶, Wouter van de Bund⁷ & the AMBER Consortium

Organisation and country:

¹Swansea University (UK), ²POLIMI (Italy), ³CNSS (France), ⁴WFMF (Netherlands), ⁵Durham University (UK), ⁶Southampton University (UK) & ⁷European Commission DG Join Research Centre (Italy)



INTRODUCTION

Rivers rank among some of the most threatened ecosystems in the world and are the focus of exorbitant restoration programmes that cost billions to taxpayers. One of the major problems rivers face is habitat fragmentation and loss of connectivity caused by man-made barriers. Stream barriers break river connectivity, cause a loss of ecosystem services, and exacerbate the impact of extreme climate events such as droughts and flooding. But barriers also provide energy, water, fishing and leisure opportunities, and may also help to prevent the spread of aquatic invasive species. Some barriers are old and out of use, but may have historical value. The life span of others will soon come to an end and may need to be removed. Thus, effective rehabilitation of stream ecosystem functioning needs to account for the complexity and trade-offs of barriers; for this, a good barrier database is needed.

Some estimates, based on extrapolation from regional surveys, suggest that there may be over a million stream barriers in Europe (Garcia de Leaniz, 2016), but nobody knows for sure, as there is no global barrier database available beyond information on large dams (i.e. GRanD; Vörösmarty *et al.*, 2010). For this reason, one of the main objectives of the EU-funded AMBER project (Adaptive Management of Barriers in European Rivers, www.amber.international) is to produce a Pan-European Atlas of Stream Barriers that can help water managers prioritize restoration efforts, inform mitigation measures and make better restoration decisions.

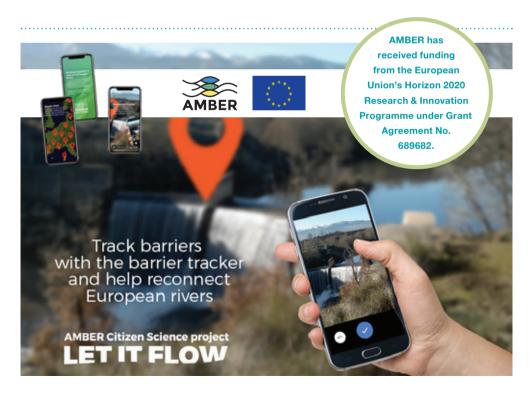
WHAT DID WE DO?

Unlike in North America, China or Australia, many of the large rivers in Europe cross international boundaries. Different countries differ in the way the information on barriers has been collected, the spatial coverage, and even what is considered a barrier. For example, some countries only hold information on dams greater than 15m in height, while others include small weirs or even culverts at road crossings. Many barriers are small and cause little fragmentation, while the location and characteristics of some equally small can have a major impact on river connectivity. The EU Water Framework Directive requires river management at catchment scale. However, it is difficult to prioritize local barrier mitigation efforts without having a complete overview of all the barriers at the catchment scale. Given that the problem of restoring stream connectivity transcends political boundaries, it is important that a common barrier database is used, one that uses a common methodology for recording and reporting barriers.

HOW DID IT WORK OUT?

To this end, a Barrier Assessment Workgroup was formed and a workshop held soon after the start of the AMBER project. The Workgroup defined the type of barriers that would be recorded in the Barrier Atlas (essentially any artificial structure causing a height difference and capable of impacting stream connectivity), the barrier typology to be used (6 main barrier types were defined), and the criteria for data verification, data validation, data reporting and long-term curation. The AMBER database is a relational database that holds information on 11 fields (including barrier coordinates, river name, barrier height, barrier type, and year of construction where known) as well as a link to the original data source. The database will be hosted by the European Commission's Joint Research Centre (Ispra, Italy) and will be freely available for all to use.

Currently, the database holds information on more than 230,000 stream barriers in 13 EU countries, but by the end of the project it will have markedly expanded, covering 33 countries. One of its distinguishing features is that is designed to be a live database, regularly updated with information provided by users via a citizen science programme and a smart phone app (Barrier Tracker available from Google Play). In this way, the AMBER Barrier Atlas will contribute towards a more effective and participatory restoration of stream connectivity across Europe.



The development of administrative units in water resource management should 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 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. However a shift has been observed with increasing roles for various stakeholder groups. Experience shows that effective collaboration between agencies and active members of the public increase the chances of success.

A good example of an institutional framework is the EU framework, which obliges development of scientific and technological development in terms of sustainable development. Water management is based on holistic river basin management with set regional and continental objectives (also see Section 5.2).

5.4.2 Decentralization of river basin management

Decentralization and increased stakeholder involvement are widely being promoted worldwide as ways towards 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 suggested that water scarcity can be used to reform and unite stakeholders in the basin and can lead to a better focus on the river basin management cycle.

5.5 RIVER BASIN APPROACH

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, should be considered together with the constraints to their habitat. Important questions to consider include 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 indigenous species. Pragmatically, it is often necessary to focus ambitions on agreed priority waters and to set targets for certain species or a group of species.

5.5.1 Strategic objectives

For each river within the basin, objectives for fish migration should be defined. An objective might be, for example, to achieve free migration (upand downstream) of target species from sea to source. Where this is not possible, perhaps due to overriding 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 always seek to protect and enhance the migration potential for all of the fish species present. The objectives should complement and support the overall ecological objectives for the river basin and they should therefore be integrated within local plans of appropriate partner organisations.

Criteria for selection of target species include:

- They have access to their full original distribution in the river basin;
- There is a realistic chance for restoration of a sustainable population;
- They have a high requirement for connectivity of habitats and habitat quality;
- They are part of national or international policy;
- · 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 free-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

THE THREE BASIC STEPS

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 downstream.

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 an ecological status defined by ecological targets.

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, location of dams, stream connections, quantitative estimates of habitats and other potential obstacles or opportunities for fish passage protection or restoration.

STEP 3

For both upstream and downstream migration

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

Priorities of measures

EXAMPLE

Fish and hydropower in the Lower Mekong Basin in Lao PDR

Authors: Organisation:

Country:

Zeb Hogan & Teresa Campbell Global Water Center, University of Nevada, Reno Lao PDR



INTRODUCTION

The Mekong River originates in the Tibetan highlands and passes through China, Lao PDR, Thailand, Cambodia, and Vietnam. The Upper Mekong flows through a steep and narrow catchment and has less productive fisheries; the Lower Mekong is characterized by complex tributary systems and floodplains and contains species that provide food security and livelihoods for millions of people. It also supports some of the world's largest, most endangered fishes.

THE XAYABURI DAM IN LAO PDR UNDER CONSTRUCTION

This is the first mainstem dam on the Lower Mekong. © Suthep Kritsanavarin.



The natural flow pattern-the flood pulse-is a key driver of the extraordinary fisheries productivity and biodiversity (almost 1,000 documented fish species) of this region (Baran and Myschowoda, 2009). The fisheries of the Lower Mekong Basin produce approximately 2.5 million metric tons per year and are valued at US \$3.6-6.5 billion annually (Ferguson *et al.*, 2011).

In 2010, plans for the first mainstem dam on the Lower Mekong-Xayaburi Dam in Lao PDR-were brought before the Mekong River Commission (MRC), an advisory body formed by Lao PDR, Thailand, Cambodia, and Vietnam, that works to ensure sustainable development of the basin. Experts predicted severe environmental repercussions (Stone, 2016). Barring serious mitigation measures, the dam could affect as many as 129 fish species, adding another 10 species to the endangered or critically endangered lists (Baran *et al.*, 2011) and leading to the extinction or extirpation of at least 4 of the world's largest freshwater fish (Hogan, 2011).

ACTIONS UNDERTAKEN

The potential magnitude of the dam's disruption of food security, livelihoods, and environmental services (and the precedent it would set for future development) led to a call by the MRC for a 10-year moratorium on hydropower development to give scientists time to research fish mi-

BAAN PAK LAAN

At Baan Pak Laan, fishermen use their traditional fishing method to harvest from Mekong River. This way of life will be lost if the dam is built. © Suthep Kritsanavarin.



gration patterns and habitat use (many of which are poorly understood), how those will be affected by dams, and to assess effective mitigation techniques (Vaidyanathan, 2011).

The proposal prompted a flurry of fisheries research. Scientists worked to acquire baseline information on important species' ecology and population status as well as estimating the value of the fishery in order to refine predicted impacts and assess actual impacts of dam construction (Vaidyanathan, 2011).

OUTCOMES

Despite the predictions of significant environmental degradation (Baran *et al.*, 2011) and the pushback from other MRC countries, Lao PDR began construction of Xayaburi Dam in 2010. The Xayaburi Power Company dedicated a reported US\$400 million to environmental impact mitigation. However, the benefits of these mitigation measures are unclear. Construction is underway on two more dams close to the mainstem and more are in planning stages (Stone, 2016). Together, these barriers will significantly alter the hydrology of the Lower Mekong and may eliminate endangered species (Baran *et al.,* 2011).

LESSONS LEARNED

Lao PDR has been referred to as "the battery of Asia", Cambodia as the region's "fish factory", and the Mekong delta as the "rice bowl" of Vietnam. These visions underscore the reliance of the region on the Mekong River and the delicate balance between economic prosperity and environmental health. Maintaining both will require a strategic and collaborative approach to hydropower development at the government level. While important for facilitating international cooperation, the MRC's mandate is advisory, not governing. Furthermore, baseline data on the value of natural resources and requirements of important species are critically needed for decisionmakers to appreciate the full costs and benefits of developments.

and native fish stock management, and for natural and ecological targets, and should hopefully gain broad social acceptance. Objectives must be at least to achieve "no detriment" for fish passage and this should ensure no further decline in the species due to ongoing habitat fragmentation and blockage of migration routes. Some rivers will be so modified, as a result of past urbanisation and industrialisation, that full realisation of potential is currently economically unrealistic. However, there should be a clear objective or aspiration to achieve much more through the restoration of fish migration routes wherever possible.

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 with much effort by all EU member states under the Water Framework Directive (European Commission, 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. Reaching these objectives will be costly and time consuming, but a huge benefit for the people and ecosystems of Europe.

Dam removal

Dam removal is often seen as one of the most valuable measures to restore rivers and fish migration routes. © Jeroen Helmer.



5.5.2 Prioritising 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. An assessment in England and Wales (UK) identified in excess of 25,000 such obstructions.

It is not necessarily the case that all obstacles must be made passable for fish to achieve the relevant objectives and although desirable it might not be affordable. It is then important to prioritise rivers, for example by selecting 'natural waters' as priorities, followed by the 'heavily modified waters' and then the 'artificial water bodies'. Each might be important for sustainable existence of some target species. Alternatively, selections of priority 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 basis of drainage direction, but also by seeking local experience regarding historic distribution and current habitat quality. In opening migration routes, it is important to secure passage progressively, working upstream for anadromous species. It is also important to maximise uptake of opportunities when and where they arise, working towards an overall strategic objective and vision for the watershed. 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, dam licensing, water management, ecological restoration, etc.) that might give rise to more cost-effective solutions. The outcome of

Figure 5.1 Ecological prioritisation regarding measures for river and habitat continuity

The Iron Gate Dams on the Romanian - Serbian border are indicated as 'Utmost Priority for long distance migrants'. Danube River Basin Management plan, update 2015. © International Commission for the Protection of the Danube River (ICPDR).



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 that 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 of the historic fish can be restored or even sustained. Even when fish passage and survival at some sites is as high as 95%, the cumulative impact of a succession of barriers can lead to unsustainable losses. 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 a reasonable potential to restore them.

5.5.3 Prioritizing restoration measures

Once priority waters have been confirmed, potential solutions to the obstructions to migration can be identified. The full restoration of fish migration routes in river systems may be a very difficult and impractical goal, especially when a chain of many obstacles needs to be addressed. In most cases it is simply not possible to resolve all or even many of these at once. For this reason a phased approach is often required. Prioritisation for action should be on the basis of

FXAMPLE

From Sea to Source. Targets for fish migration in river basins in the North of the Netherlands

Authors:

Country:

P.P. Schollema¹ & H. Wanningen² Organisations: 1Regional Water Authority Hunze en Aa's & ²World Fish Migration Foundation Netherlands



VISION "FROM SEA TO SOURCE"

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

One of the important principles for the partners was the need for a structured approach to prevent further decline of the potential for fish migration in the region. 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 very different solutions, and the vision sets objectives for representative fish species in each of these different areas.

THE VISION HAS TWO THEMES:

- 1 Prevention of further deterioration of fish migration potential (the "stand-still" or "no detriment" principle);
- 2 Solutions for migration bottlenecks were identified in the vision. The vision prioritizes the bottlenecks by creating a so-called fish migration map that identifies all bottlenecks

in the management area. The advantage of such a map is that the bottlenecks are clearly visible and it is clear to see which bottlenecks have priority.

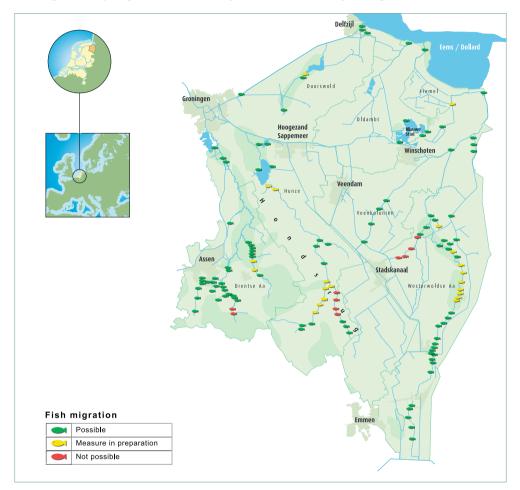
An important instrument which is used to make regional policy is the so-called ecological connection zones. These are zones that connect ecologically important areas and where the partnership seeks to ensure that fauna as well as flora can freely interchange between these areas. Rivers and brooks are often used as ecological connection zones, 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**

The shared vision and strategy has proved to be a strong tool to get measures financed and executed. In 2005 the vision showed a total number of 132 fish migration barriers in the management area of RWA Hunze en Aa's alone. By early 2017. 105 of these barriers have been removed or fitted with an appropriate fish migration facility. Good cooperation between the different partner organisations in the region has shown to be a powerful instrument to gain enough financial and technical support to accomplish appropriate solutions now and in the long run.

FIGURE 1

Fish migration map Regional Water Authority Hunze en Aa's © Curly Eissing, 2018.



We created strong partnerships with NGO's, the Angling Federation, provinces and other water authorities. By partnering we create more funding potential, and together we have grown a great feeling of pride! We are proud that we all work together on these amazing rivers and fish species.

The past decade we have followed the river basin approach presented in this book. It proved to be a successful work method. From setting the ambitions, installing fish passage facilties, setting up collaborations, finding subsidy programs, research and to starting education programs. All aspects have been tackled and improved. This work method proves to be a strong base for the protecting migratory fishes.

HYDRO BY DESIGN

Joshua Royte, The Nature Conservancy (USA)

Global hydropower development is growing rapidly. In an attempt to find a balance between energy and conservation in hydropower, The Nature Conservancy (TNC) demonstrated how system-scale approaches produced more balanced outcomes for river users.

Using a global database of current and planned dams, TNC modelled impacts to river flow patterns and loss of connectivity. The results showed that the hydropower dams under construction and planned would affect thousands of kilometres of rivers through fragmentation and changes in flow. Furthermore, these developments would influence a large of number of rivers with significant fish species diversity, including migratory fish.

To overcome these issues, Hydropower by Design recommends a system-scale approach for the designing and operation of multiple dams and basin-scale analysis for the proper planning and siting of new dams. The resulting Hydropower by Design scenarios were designed to identify spatial arrangements of dams that can maximize the length of connected river and thus reduce the amount of river length lost to fragmentation.

Quantitative case studies of hydropower development decisions show that hydropower by design can produce broader economic benefits including system design optimization as well as improved risk management and Improved environmental values compared to "business as usual" approaches (Opperman, *et al.*, 2017). The applications of this approach varied across the types of basins. One of the case studies included the analysis of the Yangtze River. By hypothetically reducing the flood storage allocations within a proposed cascade hydropower dam, it resulted in increased power generation and revenue by 10%. Investment of that revenue to reduce flood risk would thus result in overall reduction in flood risk and improve the flow regime for a Native Fish Reserve (Opperman, *et al.*, 2017).

The Yangtze River is home to some of China's most spectacular natural scenery © Michel Gunther/WWF.



Setting priorities

Regional Water Authority Hunze and Aa's is working on freely accessible river systems with a long-term fish migration plan. Spatial planning is an important part of this process. It is stated that it does not matter where in the catchment restoration measures are started first, as long as the overall ambition, a well-connected river, is achieved at the end. Photos: A) Nieuwe Statenzijl tidal gate with freshwater shower to attract eels towards a special eel fishway and B) the Hunze River restoration project. © Herman Wanningen.





criteria agreed at the outset, although opportunity and social constraints may be the primary driver of what gets done and when.

More than one solution might be identified to mitigate an obstruction. Depending on an assessment of individual costs and benefits and ecological outcome, it is preferable to select the most natural solution. A final prioritisation plan should provide an indication of resources and finance needed for each phase of action.

The protection of downstream migrants can be more difficult than it is for upstream migrants. In most significant surface water extractions, the construction of appropriate mechanical barriers would likely 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 (BAT) or Not Entailing Excessive Cost (BATNEEC) is applied. In some circumstances it may be feasible, to use 'fish friendly' turbines or dam bypasses. However, it is important to clearly demonstrate beforehand that the required standards for safe, timely and effective fish passage rates can be attained for all of the desired species. 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 operations), although this may not be as effective and compensation may still be required. A full and independent evaluation of potential technical solutions and their respective benefits for the fish species concerned is required. Technology to protect fish at water intakes is a discipline where further research is required to identify best practices. In this respect, it would be helpful to develop robust pilot programs, where damage is known to occur, to explore more acceptable solutions with the support of appropriate industrial and academic sectors.

5.6 ECONOMICS

5.6.1 Economic drivers & 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 socioeconomic 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.

In The Netherlands the DPSIR Principle is applied by the STOWA (research organisation of the Dutch Water Authorities) to develop a methodology that analyses the ecological performance of freshwater systems in a wider context. A set of 10 Ecological Key Factors for stagnant and flowing water can be used as a tool that allows water managers to analyse water quality in freshwater systems and set quality goals as part of the European Water Framework Directive. Connectivity is one of the important key factors within this methodology. (www.watermozaiek.stowa.nl)

5.6.2 Funds for fish

This section suggests various routes to help fish migration specialists find funding for river restoration projects and fish migration measures. It is not an exhaustive overview or completely up to date, 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.

In Europe, the 2006 European Fish Migration Guidance (Kroes, *et al.*, 2006) (www.hunzeenaas.nl) considered many public and private funding opportunities. These include 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 US 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 and funding mechanisms.

Free-flowing rivers are extremely rare and these, together with still uncommon 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 Water Framework Directive. For example, the Westphalia region of Germany is planning to invest € 60 million every year until 2027 to achieve this, and other countries are also planning 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 some development plans dating back many decades and, today there is growing interest in even more new plans. A strategic compromise to deal with hydropower organisations could be a mechanism to protect the remaining natural un-impounded 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. Alternative sources of more sustainable electrical generation are becoming more affordable and, given the location of the power grid to hydro dams, there may be opportunity for 'brown-stone' development of efficient wind and solar to offset losses from older and often less efficient hydropower dams. Funding allocated by governments for nature and water projects could also be used. The Columbia Dam in the USA is a great example of a successful reallocation of energy for electricity grid from hydropower to solar panels. A successful agreement between landowners, NGO's and governments resulted in installing solar panels over a trout hatchery. The benefits to all users were significant including: allowing for the removal of the dam, restoring natural river habitat, ensuring that the electricity grid is maintained with clear energy and providing the trout hatchery with a buffer to protect young trout.

Fly fishermen from The Netherlands cleaning a fishway

The Flyfishing community has a high interest in healthy and free-flowing rivers. It's a multi million euro industry and are great advocates for open rivers. Involving local fly fishermen can be crucial in the success of river restoration projects.



WORLD BANK AND HYDROPOWER DEVELOPMENT

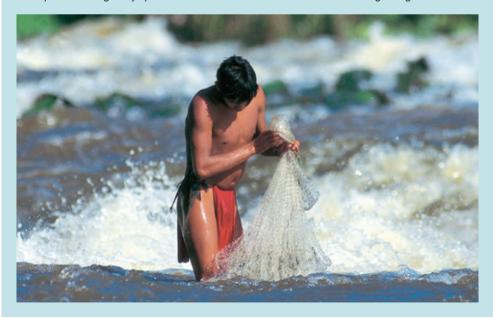
Kerry Brink (World Fish Migration Foundation, The Netherlands)

The World Bank is one of the largest sources of funding and knowledge for developing countries. Their mission is to reduce poverty and increase the incomes of 40% of the poorest people in countries in which the Bank is active. In consideration of this mission, the bank has recognized that it is imperative that ecosystems and natural resources should be managed in order to sustain long-term economic growth and well-being. The economic benefits of healthy ecosystems are crucial for both:

- · long-term growth of economic sectors such as fisheries that already provide millions of jobs;
- providing a significant safety net to 78% of the world's extreme poor who live in rural areas and are dependent on resources from rivers, lakes and oceans for food, fuel and income.

Developing countries are particularly dependent on the World Bank (and other development funders) to develop and implement strategies that ensure informed decision-making, support and promote environmental sustainability and to only invest in projects that have adequate measures in place. Within the organisation of the World Bank, the Environmental and Natural Resources Global Practice addresses some of these requirements, with a strong focus toward climate change issues (World Bank, 2017). For example, the World Bank worked with partners in Brazil to protect around 60 million hectares of Amazon rainforest that promotes conservation, socio-economic development and supports actions that will help reduce CO² emissions by 300 million tons by 2030.

Local Wayampi fisherman in the Oyapock River on the French Guiana - Brazilian border He depends on migratory species in the river for his food and income. © Roger Lequen WWF.



In Morocco, the World Bank has helped support government policies on green growth across sectors, including better management of natural resources and improving the governance in fisheries to protect the livelihoods of approximately half a million Moroccans. On a global scale, Global Environmental Facility in partnership with the World Bank approved a project to address the decline of important migratory fish stocks in both coastal and ocean areas around the world.

Within the World Bank, fisheries are a key topic, however much of the current focus is toward ocean and coastal regions. PROFISH (Global Program on Fisheries) was established to engage the World Bank and promote sustainability of world fisheries, particularly focused toward ocean and coastal regions. The Bank also provides funding for watershed management and other activities that help reduce coastal pollution.

The World Bank also plays a significant role in large hydropower developments. For instance, ensuring that hydropower developers adhere to strict standards and principles that seek to ensure limited impacts. Within the hydropower guidelines, the impact of hydropower projects is considered to have a major effect on fish and aquatic life and mitigation measures such as managed water releases, fishing regulations and fish passage facilities have been briefly documented (World Bank, 2015). In Africa, the actual extent of fish migration is still largely unknown, which makes it difficult to develop appropriate mitigation measures required to protect fish stocks. As such more needs to be done to stimulate action for further research and development to ensure sustainable developments.

Stakeholders in fishery, agricultural and other relevant 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 the larger rivers around the globe often support larger, diverse and important artisanal, subsistence and commercial fisheries. However, many studies have demonstrated plummeting stocks directly after dam development (Mol, et al., 2007; Baran, et al., 2011). Dams break the transport of sediment downstream, which leads to less fertile floodplains and agricultural land downstream and less productive waters as well. Ambitions to create fisheries within the newly impounded areas generally fail over time and cause drastic changes in the aquatic food web with species that may not be desirable for local communities. Concerted forward thinking and planning is clearly essential.

The Mekong River is a good example where

freshwater fisheries are a major driver for the economy. Dam development has had devastating impacts on fish stocks and people's livelihoods. These socio-economic issues have been a driving force for the commission of the Mekong River Basin Committee. They are seeking to establish a commitment to a more integrated management of the catchment for the benefit of the ecosystems and people living in the watershed. Tribal and indigenous land and water rights is a critical consideration finally being used more around the world to identify priorities, help local communities as well as initiate funding for sustainable development projects that can help both the environment and local cultures.

A significant challenge that, happily, has been met in most continents, is that of cross-border river management 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 of river basins where political will has secured integrated thinking for trans-boundary rivers. These programs need to guard against political complacency which can lead to the breakdown of such an integrated approach so caution is needed.

Within the realm of river planning, most notably for the larger plans, the global impact of habitat fragmentation on biodiversity and human communities and economies has not been addressed comprehensively. The rapid expansion of so-called 'green' hydropower dam development needs to be carefully examined in the context of long-term and often irreversible damage to these productive systems. Despite growing experience and advice, significant UN and EU funding is still channelled into potentially damaging dam construction projects in the developing world. It would seem sensible for some proportion of these funds to be targeted for more comprehensive holistic planning, avoidance, mitigation and fisheries protection schemes and to ensure that some rivers are kept free-flowing.

12,000 km lifecycle

The European eel (Anguilla anguilla) has a very special life strategy. The eel's eggs are laid and hatch in the Sargasso Sea, close to Bermuda. After hatching, they change from tiny larvae, to a shape like a willow leaf. Their transparency makes them difficult to see for predators. The gulf stream transports them 6,000 kilometres across the Atlantic Ocean towards Europe. Along the way they change their body shape to the transparent glasseel stage. In Europe they swim into estuaries, changing from transparent form into a brown colour, this is called the elver stage. Eventually they enter rivers, lakes and canals in their search for habitat to grow up. During the day the eels hide but at night they emerge and hunt invertebrates and small fish. Once mature, now called silver eels, they make the journey back to the Sargasso Sea where they spawn in the deep sea and then die. © Jeroen Helmer.



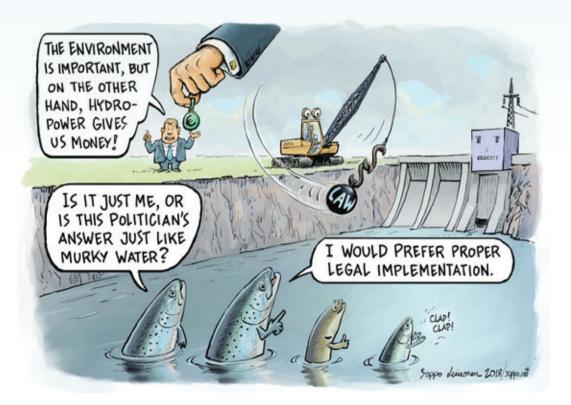
CHAPTER 6 LEGISLATION AND POLICIES AROUND THE WORLD

Save our rivers, stop the dam campaign in 2016 at Bohinj Lake in Slovenia @Matic Oblak. In the Balkans (Central Europe) over 2500 new hydropower dams are planned in pristine and free-flowing rivers (www.balkanrivers.net).

INTRO

Incorporation of migratory fish conservation and restoration into local, national and international legal systems is critical for the protection of riverine fisheries and maintenance of healthy ecosystems.

One of the earliest known laws to be passed that forbade construction of weirs that limited fish passage was in 1709 in the State of Massachusetts (Katopodis & Williams, 2012). Such laws can address local problems, however the number of stream barriers fragmenting rivers throughout the world clearly demonstrates the need for more and ongoing refinement of legislation and policy. We believe that a comprehensive river basin approach for fish migration is required to guide governments to the appropriate scale for collective policy at national and sometimes international levels. In this chapter we describe some of the legislation and policies relating to fish migration for each continent. We present an overview of the main global treaties, conventions, multilateral and bilateral agreements as well as a multitude of national policy directives, laws and regulations.



6.1 PROTECTING MIGRATORY FISH WITH INTERNATIONAL LAWS AND AGREEMENTS

There are several major global agreements, policies and regulations relevant to fish migration. In these, governments are obliged to comply with international agreements and conventions to promote inland fisheries restoration, wise management and conservation. Some agreements highlight or profile important or charismatic flagship species of migratory fish (Valbo-Jorgensen, *et al.*, 2008). Some advantages of promoting flagship species with these agreements are:

- It is easier to gain public interest and heighten the profile of threatened species;
- It can attract the interest of policy makers to the need and mechanisms for preserving biodiversity and fish production;
- It can provide a starting point for negotiations among countries sharing resources and management responsibilities;
- The singular focus makes finding consensus easier when developing priorities and actions between two or multiple countries.

An example of such high-profile fishes are the sturgeons and paddlefishes. There are currently 23 sturgeon species that have a declining conservation status and, as of August 2017 are on the IUCN Red List, and also in Appendix II of CITES. This, together with legislation and transboundary basin management plans, can be used to focus management efforts and ultimately protect these species.

6.2 GLOBAL LAWS AND AGREEMENTS - THE PRINCIPLES

There are a number of major global conventions that have been signed by multiple countries around the world in order to protect migratory fish either directly, or indirectly. Here are a few:

IUCN

IUCN (the International Union for Conservation of Nature) Red list focuses on the identification and 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. The IUCN is currently the global authority on the status of the natural world, and the measures needed to safeguard it. It sets definitive international standards for species extinction risk. These evaluations are relevant to governments and institutions at all levels because they can be used as a starting point to identify species that have an unfavourable conservation status and to set targets for action.

The Bonn Convention

The Bonn Convention (The Convention on Conservation of Migratory Species of Wild Animals, known as the CMS convention) was signed in 1979 and came into force in 1983. It is a global Convention with over 120 member states currently. Most notably, it is one of key global agreements designed specifically to facilitate management and conservation of transboundary migratory species (Hogan, 2011). The Convention addresses the protection of migrating wild animal species (defined in appendices I and II), while Section 2 recognises the importance of migrating fish species and requires appropriate measures to be taken to protect them. Currently sturgeon and paddlefish are in Appendix II (Table 6.1).

Although there are some important regions with migratory fish species that are not signatories of the CMS convention, they can participate in regional agreements and through collaboration with other international agreements as specified below (Hogan, 2011).

The Rio Convention

The Convention on Biological Diversity, UN, 1992 arose from the Earth Summit held in Rio de Janeiro in 1992 and relates to UNFCCC (the United Nations Framework Convention on Climate Change), and to CBD (Convention on Biological Diversity).

The 'Earth Summit', attended by 170 countries and over 2,000 NGOs, concerned with the con-

FXAMP

Segura-Riverlink project: a green infrastructure approach to restore the longitudinal connectivity in Mediterranean river basins

Authors: **Country:**

Francisco J. Oliva-Paterna¹, Francisco J. Sanz-Ronda² & Rosa Olivo del Amo³ Organisations: 1University of Murcia, 2University of Valladolid & ³WFMF Spain



INTRODUCTION

Habitat fragmentation and loss of connectivity caused by small barriers are major factors in shaping fish assemblages. However, few tools are developed to restore these attributes in Mediterranean river basins. Segura-Riverlink is a LIFE Programme project (2013-2017 action period) which aimed to promote and support the environmental recovery of a fluvial sector in a highly impacted river basin located in the Southeast of Spain (Oliva-Paterna et al., 2016a). The main purpose was to validate management measures for the development of a Green Infrastructure approach in the Segura River Basin which is one of the most intensively regulated basins in the Iberian Peninsula.

WHAT DID WE DO?

The project restored longitudinal connectivity (in more than 50 km of mainstem river) through the removal of a small unused weir (January 2014) and the construction of four natural-like fishways (three bypasses and one rock-ramp) and four vertical-slot fishways which have been designed according to the unique characteristics of each site (Oliva-Paterna et al., 2016b). Moreover, a fish-based monitoring programme was implemented to assess the effectiveness of the

fish passes (Sánchez-Pérez et al., 2016) and determine the abundance of sentinel or target species before and after the construction of these infrastructures.

Other best practices of riverine restoration, such as increasing the area of riparian forest or creating a Land Stewardship Network to involve different stakeholders in river management and in agreeing good practices, were developed by CHS (Administrative organism of the Segura River Basin, Coordinating Beneficiary) and other members of the project consortium.

HOW DID IT WORK OUT?

From January 2016 to December 2017, more than 12,000 individuals of nine fish species were collected inside the fishways. Sentinel species of the project which normally show seasonal movements accounted for 98% of the total captures: bleak (49.9%), Pyrenean gudgeon (35.7%), Iberian nase (6.6%) and Southern Iberian barbel (5.8%). Higher captures inside the fish passes were detected during their reproductive movement periods. However, use of the different fish passes by these sentinel species showed differences in temporal patterns. For instance, Pyrenean gudgeon appear to be the species that shows best adaptation to new microhabitats created inside the fish passes.

LESSONS LEARNED

Experience has shown that the most effective means to develop successful solutions occurs when engineers and biologists work together systematically to design passage structures, as happened in the Segura-Riverlink project (www. segurariverlink.eu). Our fishway design process for upstream migrating fish has provided an opportunity to develop safe, timely, and effective fish passage structures. Moreover, an exhaustive and complete fish-based monitoring program to assess the effectiveness of fish passes should be an essential part of any project.

The project outcomes have protected local aquatic and riverine habitats, allowed fish reproductive movements along an important fluvial sector, improved ecosystem services, and built a framework of scientific and social knowledge to improve river management quality and to help the implementation and enforcement of EU policy and legislation on biodiversity conservation.

FISH PASSES IMPLEMENTED IN THE SEGURA-RIVERLINK PROJECT

Views of by-pass and vertical-slot fishways (A and B). Fish sampling in progress in the fish passes using methods developed in the monitoring program (C and D).









servation of all global species and ecosystems and was intended to secure increased protection of global biodiversity. It was also intended to promote awareness and activate cooperation from local people as well as building national and international capacity and capability. 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.

Fish as flagship species

A) White sturgeon (Acipenser transmontanus) caught for research in North America. Sturgeon species occur worldwide and are flagship species for many rivers. © Zeb Hogan. B) Herting River Restoration project at Falkenberg, Sweden. Symbolic release of salmon smolts by His Majesty King Carl XVI Gustav of Sweden. The ultimate goal is for salmon, eel, sea lamprey and other species can migrate freely again in the River Ätran. © Herman Wanningen. C) Sea trout released in the context of a reintroduction plan in the north of The Netherlands. © Herman Wanningen.

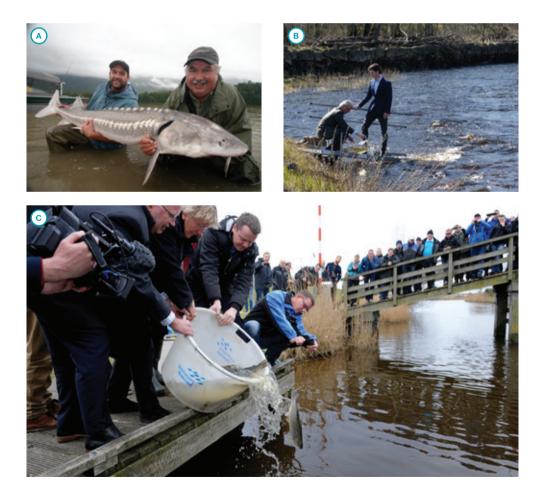


Table 6.1 Fish species in the CMS and CITES appendices (CMS, 2015)

Animals (effective June 2015)		
Acipenser baerii baicalensis	Siberian sturgeon	Appendix I
Acipenser fulvescens	Lake Sturgeon	Appendix I
Acipenser gueldenstaedtii	Russian Sturgeon, Ossetra	Appendix I
Acipenser medirostris	Green Sturgeon	Appendix I
Acipenser mikadoi	Sakhalin Sturgeon	Appendix I
Acipenser naccarii	Adriatic Sturgeon, Italian Sturgeon	Appendix I
Acipenser nudiventris	Ship Sturgeon, Spiny Sturgeon	Appendix I
Acipenser persicus	Persian Sturgeon	Appendix I
Acipenser ruthenus	Sterlet	Appendix I
Acipenser schrenckii	Amur Sturgeon	Appendix I
Acipenser sinensis	Chinese Sturgeon	Appendix I
Acipenser stellatus	Stellate Sturgeon, Sevruga, Star Sturgeon	Appendix I
Acipenser sturio	Common Sturgeon, Atlantic Sturgeon,	Appendix I
	Baltic Sturgeon, German Sturgeon	
Anguilla anguilla	European eel; Common eel; River eel;	Appendix I
	Weed eel	
Huso dauricus	Kaluga Sturgeon	Appendix I
Huso huso	Giant Sturgeon, Beluga	Appendix I
Pangasianodon gigas	Giant Catfish	Appendix I
Psephurus gladius	Chinese Paddlefish, Chinese Swordfish,	Appendix I
	White Sturgeon	
Pseudoscaphirhynchus fedtschenkoi	Syr-Dar Shovelnose	Appendix I
Pseudoscaphirhynchus hermanni	Small Amu-Dar Shovelnose	Appendix I
Pseudoscaphirhynchus kaufmanni	Large Amu-Dar Shovelnose, False	Appendix I
	Shovelnose, Shovelfish	

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List of some fish species within the CITES Appendices		
Acipenser brevirostrum	Shortnose sturgeon	Appendix I
Acipenser sturio	European Sea sturgeon	Appendix I
Chasmistes cujus	Cui-ui	Appendix I
Anguilla anguilla	European eel	Appendix II
Caecobarbus geertsii	Congo blind barb	Appendix II
Probarbus jullieni	Jullien's golden carp	Appendix I
Arapaima gigas	Pirarucu	Appendix II
Pangasianodon gigas	Mekong giant catfish	Appendix I
Hypancistrus zebra (Brazil)	Zebra pleco	Appendix III

CITES

CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora. The CITES convention was signed in 1973 by 80 parties to protect endangered species against overexploitation, by preventing international trade. By 2017, the number of signatories had more than doubled to 183 countries. These countries have all made formal declarations to this legally binding agreement. In this convention there are three different Appendices, which include lists of species afforded with different levels of protection.

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 across international borders, 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 167 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 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.

Sustainable Development Goals 2016

Sustainable Development Goals 2016 replaced the Millennium Development Goals, MDGs, from 2000. In 2015, 193 UN member states adopted new sustainable development goals for 2030. There are 17 different goals, which includes those specific to taking urgent action on climate change, improving water quality and conserving biodiversity. As was the case for the MDGs, The Food and Agriculture Organisation of the United Nations (FAO) is working with the international community to achieve these goals, some of which are relevant to migratory fish (FAO, 2017).

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 important wetlands and to achieve sustainable development of these wetlands. Wetlands achieving certain criteria are included in the "List of Wetlands of International Importance". This is of direct relevance to fish migration through selected wetlands as described in the handbooks on Wetland Policy (Ramsar Convention Secretariat, 2010a), River Basin Management (Ramsar Convention Secretariat, 2010b) and International Cooperation (Ramsar Convention Secretariat, 2010c) which signatories have all committed to.

Paris Convention

Convention for the protection of World Culture and Natural Heritage, 1972. This convention recognizes the way people and nature interact and the fundamental needs to preserve the balance between the two. There are 193 states that have committed to protect world heritage sites and preserve their legacy for future generations. UNESCO is custodian of the convention, through the World Heritage Centre that coordinates its daily management. As a number of the World's Heritage Sites are connected to aquatic ecosystems, this convention is relevant to the conservation of migratory fish. Each country contributes toward a World Heritage fund, which supports research.

Convention for the Conservation of Salmon in the North Atlantic

The convention was created in 1983 and created the North Atlantic Salmon Conservation Organization to contribute to salmon conservation through consultation on restoration, enhancement, management in all the member countries; Canada, Denmark, Greenland, EU, the UK, Ireland, Norway, Russian Federation, US, Iceland, Finland and Sweden

Convention for the Conservation of Anadromous Stocks in the North Pacific

The convention was developed in 1992. The North Pacific Anadromous Fish Commission was initated under this convention to provide a mechanism for international cooperation promo-ting the conservation of these fishery stocks. This includes the Canada, US, Russian Federation, Republic of Korea, and Japan.

Other key Conventions that protect migratory fish:

- UN moratorium on large driftnets: discourages use of driftnets on high seas;
- Stockholm Declaration 1972 (principle 21): aims to reduce transboundary impacts to environment;
- · MARPOL: Aims to reduce ocean pollution.
- Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (2000)

For more detailed information per country and region, the FAOLEX database has updated national legislation, policies and bi- and multilateral agreements on natural resources management (FAO, 2018) as well as UNDP-GEF International waters Project (UNDP-GEF, 2011).

6.3 LEGISLATION AND POLICIES AROUND THE WORLD

6.3.1 North America

The countries of North America (Canada, the USA and Mexico) have important transboundary 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 Pacific Salmon Treaty signed in 1985, as well as the Great Lakes Water Quality Agreement and the Boundary Waters Treaty of 1909.

To the south similar initiatives, including the Integrated Border Environmental Program address water resource management issues. The fact that these agreements have been developed and persist over time and multiple administrations is a testament to the critical need to address and resolve transboundary matters relating to cross-border rivers and their management. Maintenance of such agreements may be challenged in the future by changing political imperatives, but the underlying need for coordinated agreements is clear.

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

The Canadian Government fulfils its constitutional responsibilities for fisheries through two key acts: the Fisheries Act, 1985 and the Species at Risk Act, 2002, while the US has a number of other legislative acts, detailed below. The states and provinces of both countries have worked together to develop a system to identify stream barriers, prioritize habitat for restoration and fund barrier removal and other remedial actions to restore healthy free-flowing rivers and streams draining to the Great Lakes (GLRC, 2005).

Mississippi paddlefish (Polyodon spathula)

The Mississippi Paddlefish is closely related to the sturgeons and was in existence long before the dinasaurs appeared.



USA

In the USA, at least five federal agencies deal with fish migration issues on a national level, foremost the U.S. Fish and Wildlife Service (FWS) and National Oceanic and Atmospheric Administration (NOAA) - National Marine Fisheries. Others include, U.S. Department of Agriculture's Natural Resource Conservation Service, the Bureau of Indian Affairs, and the U.S. Forest Service which recently celebrated restoring fish passage at 1,000 road stream-crossings. These agencies are responsible for the enforcement of various federal laws that affect fish, wildlife, and the lands and waters they need to thrive. Among the federal acts described below, several are relevant to migratory fish and have led to additional efforts to provide effective fish passage structures, river restorations and removal of barriers (see Chapter 7). Here are some of the key acts:

- Endangered Species Act (1973);
- Anadromous Fish Conservation Act (1965);
- The Wild and Scenic Rivers Act (1968);
- Fish and Wildlife Coordination Act (1934);
- · Federal Power Act (1920), as amended in 1935;

Harvesting salmon

Salmon harvested near the confluence of the Baker and Skagit rivers. The Baker River salmon fishery is especially important to Upper Skagit tribal fishermen. It's one of the few opportunities the tribe has to exercise treaty fishing rights at the site of an ancestral village. Washington State, USA. © Herman Wanningen.



- Clean Water Act (1972);
- · Federal Environmental Policy act (1970); and the
- Alaskan Anadromous Fish Act, Alaskan Fishway Act and Subsistence fishing regulations.

An example of the positive effect of the Endangered Species Act (1973) is the reoccupation in 2009 of historic habitat for a number of endangered river fishes in the Colorado and Yampa Rivers. NOAA, in conjunction with the USFWS, has produced Restoration Plans 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*).

In addition to the federal laws, there are also individual state statutes, regulations, departmental guidelines, procedures and best practices that support improved fish passage, deals with fish directly or that regulates instream activities to benefit stream ecosystem health.

6.3.2 South America

In Latin America, countries are at multiple levels and stages of socio-economic development and environmental regulation. As such, the level of expertise available to manage water issues varies tremendously (Tortajada, 2001). In spite of this, there is a general trend toward river basin management. Several treaties, agreements and protocols have been established to inspire the collaboration around water issues, most notably in the Amazon, Magdalena, Parana, Pilcomayo, Plata and Uruguay River basins. The International Water Law Project summarises the specific law and policies related to these basins (www.internationalwaterlaw.org).

The Declaration of Asunción on the Use of International Rivers (1971) is a transboundary declaration, signed by foreign ministers of the countries of the River Plate Basin including Argentina, Bolivia, Brazil, Paraguay and Uruguay. This declaration states that permanent structures constructed on or near rivers will not interfere with other uses of the river system and includes ensuring the conservation of living resources (FAO, 1998). Another transboundary treaty includes the Amazon Cooperation Treaty (1980).

Brazil has by far the most accessible information pertaining to legislation and is recognised as one of the most advanced countries in these regards (in the region) with a national legislation that significantly protects migratory fishes (Carolsfeld, et al., 2003). For many decades, environmental legislation in Brazil has focused on fish stocking and control of fisheries as well as the construction of fish passage structures to minimise the effects of barriers on migratory species (Pompeu & Martinez, 2007; Carolsfeld, et al., 2003; Agostinho, et al., 2002). There is a long history of fish passages in Brazil, dating back to 1911. The first fish ladder constructed was at the Itaipava Dam in 1911, followed by a second ladder at the Cachoeira das Emas Dam in the early 1920's. In 1927, the São Paulo State implemented a law that was controversial at the time, that mandated the construction of fish ladders on all new dams (Gough, et al., 2012). By the 1960's other Brazilian states also incorporated legislation that mandated fish passage, as a result of the increasing number of hydro-electric facilities and growing impacts on waterways. The mandatory approach, specified for example in the São Paulo State Law 9.798/1997 and Minas Gerais State Law 12.488/1997, both require the construction of fish ladders in dams built in State domain watercourses. These are now considered by legislators, scientists, practitioners and the public, the best (and often only) measure to facilitate fish migration.

There is an increasing concern that fishways are not always the best strategies to protect fisheries (Pelice & Agostinho, 2008; Pompeu, *et al.*, 2012). For instance, the lack of monitoring and specific studies, has limited knowledge on the effectiveness of fishways. For example, there is generally a poor understanding of piracema fish and their migrations and this has led to a number of fishway designs that are either not efficient at attracting or passing fish or both (Godinho & Kynard, 2008).

Dorado (Salminus brasiliensis)

The Dorado got its name from the Portugese, dourado meaning 'golden'. This gold coloured predator is also known as "tigre del rio" (river tiger).



It is apparent that these fishways do not take into account the biological processes that are affected by river damming (e.g. blockage of migratory routes, effects on recruitment and mortality rates, spawning and early development sites, ecological traps). Suitable management measures for migratory fish conservation should be based on ecological and biological studies, incorporated into the scope for environmental licensing of each dam, and not in law enforcement.

Elsewhere in South America there are many laws that protect fish and their environment, however those specifically related to fish migration are not as clearly accessible online as those for Brazil. For countries such as Argentina, Paraguay and Boliva, the legislation is summarised by Carolsfeld, *et al.* (2003). In their review, they provide detail of fisheries legislation and regulations, with various laws mandating fishing seasons, permit restrictions, among other provisions.

EXAMPLE

Construction regulations for new dams in Brazil

Authors: Organisation: Country:

João Henrique Pinheiro Dias & Hugo Marques São Paulo State University Brazil



Brazilian regulations for environmental protection relating to new dams are derived from the National Policy on Environment (Law 6.938/1981) and regulated by resolutions of the National Council on Environment. Exploitation of the potential for energy supply of large river basins is planned by the federal agency Energy Research Company, which develops an Integrated Environmental Evaluation of proposed projects. The aim of this is to seek a balance of energy generation objectives with the conservation of biodiversity, the maintenance of genetic resources and socio-economic development at the basin scale for both existing dams and those in planning. Each new proposal requires a Project License, supported by Environmental Impacts Studies that can certify environmental feasibility and identify requirements and conditions for a subsequent phase of development. A license authorizing construction must include the environmental specifications previously identified. After successful fulfillment of all requirements, the Operation License establishes the environmental conditions for plant operation.

Licenses can be granted by Federal, State or County Government, depending on the location, scale and potential magnitude of impacts of the dam project. The responsible environmental agency must establish a Reference Term for studies on the potential damage and benefits arising from the project, as well as its environmental programs. The Reference Term is a key point of the process, as it defines the scale and scope together with the future development of environmental studies.

Some current regulatory problems must be highlighted. For example, in state-regulated projects, environmental licensing is determined by the state agency, yet environmental impact beyond the state borders may occur including impacts on hydrological regimes, migratory species and their routes, access to spawning sites, and impact on demographics and genetic flows among other aspects.

Small dams (up to 30 MV/h) are approved by a simplified environmental licensing procedure that can sometimes fail to take account of their cumulative and synergistic impacts in the river basins. In the headwaters of the Paraguay Basin, which forms the Pantanal Biome, there are 41 hydropower plants currently operating and 96 in development. Most of these are small schemes and therefore fall under simplified state licensing, even though they may affect a whole biome in three different countries. In the Upper Paraná Basin, there are three small dams planned for

the Verde River, a very important tributary for the maintenance of populations of several migratory fish species in the Upper Paraná Basin (Da Silva *et al.*, 2015). Those projects are also under state licensing, despite impacts that will spread far beyond the directly impacted river.

These problems are aggravated by the existence of some state laws that enforce the construction of fish passages, independent of environmental licensing. This can lead to useless fish passages, or even operation of inappropriate fish passages that act as ecological traps (Pelicice & Agostinho, 2008). Another imminent threat to migratory fish in Brazil is currently in debate in the National Congress. This is a one sentence constitutional amendment (PEC-65), a proposal in which just the submission of an environmental impact assessment would be enough for the implementation of a dam project that could then not be canceled because of the nature of the new amendment (Fearnside, 2016). If approved, this will be a retrograde step on Brazilian environmental regulations and will drive large-scale losses to Neotropical fish biodiversity.

NEW DAMS IN BRAZIL

Construction of the Teles Pires hydropower dam in the Teles Pires River, Brazil. © Zig Koch, WWF.



6.3.3 Europe

In the European Union, the European Commission (EC) is responsible for proposing community-wide legislation and ensuring that it is enacted. Modern regulation of environmental threats and problems is increasingly effective within the EC. There are several laws that the EC has put in place to protect nature, biodiversity and water. The most applicable to migratory fish protection is the Habitat Directive (within the Nature Directives) and the Water Framework Directive.

These EC directives are incorporated into national legislation and may be supplemented by more customized, more restrictive national legislation. In many cases, direct funding of initiatives to achieve objectives is supported by 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 required international obligations. This is leading to increased targeting of national funds to address local needs for environmental management, including those for migratory fish protection. The more significant European legislation that is directly relevant to the restoration of fish migration is discussed below. More information can be obtained from the EC website: www.ec.europa.eu

Habitat Directive (Directive 92/43/EEC)

This directive is concerning the preservation of natural habitats of wild flora and fauna, dated 21 May 1992. This directive aims to establish a 'favourable conservation status' for specific habitat types and species of EC interest. Under this directive approximately 1,200 European species, which are considered to be endangered, vulnerable, rare and/or endemic, are protected including numerous fish species, including several sturgeon, lamprey, salmon and shad species.

In accordance with the Habitats Directive (as well as the Birds Directive) a European ecological network known as 'Natura 2000' has been established. Natura 2000 is a network of representative protected areas, which provides protection to Europe's most important and threatened species and habitats. It is currently one of the largest coordinated networks of protected areas in the world, stretching over 18% of the EU land area and 6% of the marine territories.

In 2004 the EC announced that the nature directives would be evaluated via a 'Fitness Check'. This fitness check was put in place to examine the performance in terms of effectiveness, efficiency, relevance, coherence and EU added value. The results of the first fitness test were published in late 2016, and concluded that, within the framework of broader EU biodiversity policy, these areas remain highly relevant and are fit for the desired purpose.

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 required by 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 Directive is focused toward integrated river basin management, which means that the River Basin Management Plans developed under the Directive are developed for entire river basins or catchments. In this way, the Directive promotes cooperation among governments and across national borders. The aim of the Directive is to deliver a 'Good Ecological Status' in each river basin including the protection and restoration of populations of migrating fish such as salmon, eel and trout.

The WFD has the following key objectives to streamline water policies in terms of objectives and means (European Commission, 2016):

- Expanding the scope of water protection to all waters, surface waters and groundwater;
- Achieving "good status" for all waters by a set deadline;

- · Water management based on river basins;
- · Coordination of measures among governments;
- Basin Management Plans with defined, measurable objectives;
- Public participation: getting the citizens involved more closely;
- Streamlining legislation: including repealing older directives;
- · Adequate water pricing: getting the prices right.

The WFD is the most substantial legislation in Europe relevant to ecological condition, including the well-being of migratory fish. WFD effectively requires member states to ecologically optimise the use of rivers to the greatest extent practicable. This extends to targets for fish stocks and migration.

In 2006, ecological monitoring programs were first implemented, refined and calibrated to be consistent among different countries. Three years later. River Basin Management Plans (RBMP) and associated Program of Measures was prepared for each of the river basins, which resulted in a considerable improvement in our knowledge of the status of water across the EU. A significant portion of the water bodies did not achieve the primary objective of 'Good Ecological Status' by 2015. In response to this, a significant number of exemptions were applied. In the following 6-year RBMP cycle, the WFD requires Member States to justify their exemptions in the RBMPs. The deadline for achieving the objective of 'Good Ecological Status' is now 2027.

Marine Strategy Framework Directive (Directive 2008/56/EC)

This Directive aims to achieve 'Good Environmental Status' (GES) of the EU's marine waters by 2020 and to protect the resource while maintaining marine-related economic and social activities that depend on the marine environment. This also focuses on protecting fish, including migratory fish that spend part of their lifecycle in a marine environment, i.e. catadromous and anadromous migratory fish species (European Commission, 2011).

The Bern Convention

The convention 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 signatory parties in countries where this is needed. The Convention was first implemented through Council Directive 79/409/EEC (on the Conservation of Wild Birds, known as the EC Birds Directive) and then 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 reverse the loss of biodiversity in Europe.

Treaty of the Committee of ministers of the Benelux Economical Union:

This treaty focuses on the free migration of fish species in the basins of the Benelux countries (Belgium, Netherlands, Luxembourg) and was signed 26 April 1996 M (96) 5. Section 2 of this treaty requires the governments of Benelux countries to ensure the free migration of fish species in their river basins. Priority is given to the migration of the larger anadromous and catadromous fish species to and from the spawning and nursery areas.

Council Regulation (EC) No 1100/2007 for recovery of European Eel

With this regulation Europe is moving towards managing eel migration issues. It requires that all member states establish measures for the recovery of European eel stocks. This regulation was adopted in 2007, and requires that each state prepares and implements Eel Management Plans (EMPs) to achieve a common recovery target (Gough, *et al.*, 2012). The goal is to ensure at least 40% of adult eel migrate unharmed from inland waters to the sea. This obliges member states to propose various measures such as limiting fisheries, improving river continuity by removing or bypassing barriers, reducing pollution, restocking inland waters and to reserve catches for restocking within the EU.

EXAMPLE

Restoring fish migration in the rivers of the Iberian Peninsula

Authors:

Marc Ordeix¹, Gustavo González², Fco. Javier Sanz-Ronda³ & José Maria Santos⁴.

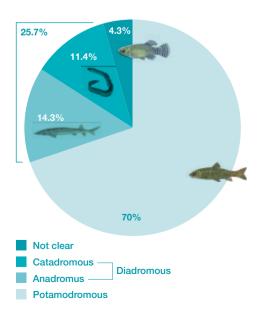
Organisations: ¹Center for the Study of Mediterranean Rivers (CERM), University of Vic -Central University of Catalonia, ²Icthios Gestión Ambiental S.L. & Centro Ibérico de Restauración Fluvial (CIREF), ³U.D. de Hidráulica e Hidrología, ETSIIAA de Palencia, University of Valladolid & ⁴Forest Research Centre, School of Agriculture, University of Lisbon.

Countries: ¹Catalonia, ^{2,3}Spain and ⁴Portugal.



FIGURE 1

Migration behaviour of Iberian freshwater fish. © Ordeix & Casals (in prep). Fish drawings: Toni Llobet". When and why do Iberian freshwater fish migrate?



INTRODUCTION

The Iberian native freshwater fish fauna consists of 69 species (Ordeix & Casals, in prep), and almost all of them (95.7%) clearly migrate during their life cycle. Their migratory movements are extensive in time, and influenced by the large variation in seasonal river discharge and water temperature that is characteristic of the Mediterranean climate. Migrations are particularly associated with the spawning period (spring for cyprinids and shads, and between autumn and spring for salmonids, among others), but also occur throughout the year for feeding and refuge. Taken together the various species in each river demonstrate some form of migration over most of the year, thus coinciding with observations from most other countries (Armstrong et al., 2010; Baudoin et al., 2014). Unconstrained movement is therefore almost a permanent requirement.

WHAT DID YOU DO?

The Iberian Peninsula (582,925 km²) has 1,794 known large dams and is therefore one of the world regions with a particularly high density

of dams. Within Spain alone there are 1,538 large dams and at least 22,000 other migratory barriers, a number which could exceed more than 50,000 as work continues on the inventory of barriers (Ecohidráulica *et al.*, 2017; Amber Project). Portugal has 256 large dams and at least 8,094 other migratory barriers.

Fortunately, the EU Water Framework Directive considers the recovery of longitudinal connectivity as a component contributing to the standard of 'good ecological status'. This guideline is reflected in Spanish legislation (the 126 bis article of the Regulation of Public Domain Hydraulic, R.D. 1290/2012. This requires the elimination of infrastructures that, within the public water domain, have been abandoned. In addition, waterboards require the installation and conservation of fish passes within barriers in order to guarantee free passage of the native ichthyofauna in all rivers. In Portugal, a ministerial order (15/MAMB/2016) required the creation of a Working Group with the purpose of identifying and studying dams and weirs and to propose a removal plan for the infrastructures that are considered obsolete.

Dam and weir removal has been increasingly used in the last few decades. At least 254 river obstacles were eliminated across Spain (Ecohidráulica *et al.*, 2017) whilst in Portugal, although only 5 river obstacles have been removed so far, more than 30 are planned to be eliminated during the next few years.

Most demolitions have been carried out in the Duero River basin and the Cantabric basins, and in the Mondego and Guadiana basins in Portugal. Likewise, more than 500 fish passes had been constructed in Spain by 2016 (Ecohidráulica *et al.*, 2017), and more than 55 in Portugal. These numbers are also increasing every year.

THE LA GOTERA WEIR

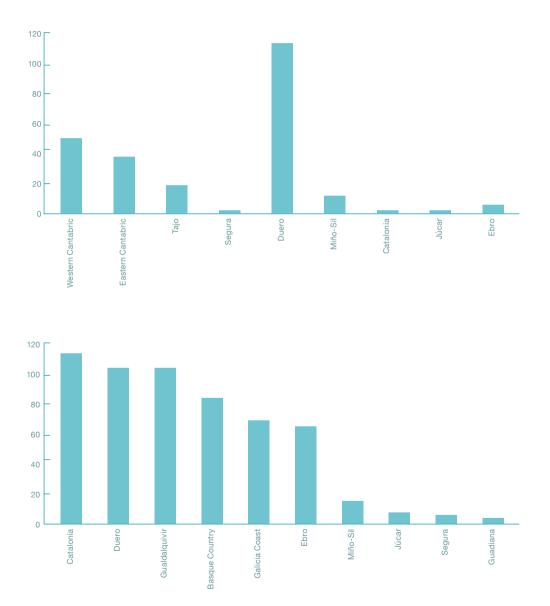
The weir (Bernesga River, Duero River basin, NW Spain), before (2011/09) and after (2011/10 and 2012/01) removal. © Gustavo González - Icthios.



>>EXAMPLE

FIGURE 2

Number of weirs removed by river basin district in Spain in the period 2006-2016 (top) and the number of existing fish passes in 2016 (bottom). Source: Ecohidráulica SL, CIREF, & Wetlands International European Association (2017).



HOW DID IT WORK OUT?

Unfortunately, dam removal and construction of fish passes is still too uncommon. Without the necessary coordination for improving fish migration on a watershed scale, many fish passes do not adequately address the requirements of native fish species or are poorly maintained.

Several in situ assessments of 'close-to-nature' fish passes, such as fish ramps built to standard guidelines (Marmulla & Welcomme / DVWK, 2002), show that they enable passage of all native cyprinid species and individuals of almost all sizes. With notable exceptions (Ibisate *et al.*, 2016), dam removal monitoring programs are very basic if they exist at all, mainly because of the inherent belief that they facilitate free migration.

There are several successful operational programs for communication and community involvement focused on the recovery of longitudinal connectivity. These include: Spanish National Strategy for Rivers Restoration, Portuguese National Strategy for the Removal of Obsolete Hydraulic Infrastructures, Life Águeda (www.mare-centre.pt), Life Cipriber (www. cipriber.eu), Life Irekibai (www.irekibai.eu), Life Miera (www.fnyh.org), Life MigratoEbre (www. migratoebre.eu), Life Segura Riverlink (www. segurariverlink.eu) and also a programme of video-monitoring of the Touvedo fish lift.

LESSONS LEARNED

Dam removal and fish pass assessments are both necessary so that we may learn more on migration periods and needs of the Iberian and Mediterranean freshwater fish fauna. This is essential for development of better projects. In addition, the high degree of ecological disconnection of the Iberian rivers is currently not recognised as an environmental constraint by many communities and so it is an ongoing necessity to communicate more and better.

EBRO RIVER NEAR THE TOWN OF FLIX, SPAIN © Herman Wanningen.



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

EC directives, treaties, legislation and policy varies considerably between countries depending the detail to which directives are transposed into domestic legislation.

It is crucial 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 basis for action on fish migration issues at the local level. Local policy should be based on national and international policy adjusted to suit specific, local conditions. Some regional or local requirements, such as planning requirements, may not be enacted as legislation while others, such as those made by federal states, municipalities or Regional Water Authorities, might.

Examples of EU Member state legislation

In Europe, there are examples of fish passage regulations that require screens or other effective barriers or diversion devices be installed to prevent entrainment of fish during water extraction for hydropower generation (Turnpenny, *et al.*, 1998).

Sea trout (Salmo trutta)

When resident in rivers this species is known as 'brown trout', but those fish of the same species that migrate to sea become silvery in colour, often with black spots and after this metamorphoses the fish are known as 'sea trout'.



In the UK, a similar regulation was enacted under each country's respective legislation for the protection of migratory fish. For England and Wales this is the Salmon and Freshwater Fisheries Act (1975), while in Scotland this is achieved through the Salmon (Fish Passes & Screens) Regulation (1994), consolidated within in the Salmon and Freshwater Fisheries (Consolidation) (Scotland) Act 2003. In Northern Ireland, this is achieved through the Fisheries Act (1966) which is currently the subject of a new Fisheries Bill (2016) to implement new powers to secure fish passage requirements.

Similarly Denmark also has formal legislation on fish screening and for the provision of fish bypasses. This is the Government Notice (Notice No. 657 of 1994) on eel passes, downstream smolt passages and fish screening in fresh waters.

In France, the legislation is not as specific and only calls for the free movement of migratory fish. This is also the case in The Netherlands, where no explicit screening legislation exists, although water extraction permits have specific conditions that protect salmon and sea trout. There are in fact many other countries that do not have formal screening regulations, including Switzerland, Poland and Sweden.

6.3.4 Asia

In Asia, there are numerous transboundary treaties and agreements for rivers such as the Amur and Mekong. There are also conservation policies for freshwater fish focused on endangered and economic species. There appears to be no specific policies currently for fish migration. In 2017 the Lao PDR's Ministry of Agriculture and Forestry did request a policy brief that summarises findings, outcomes and recommendations for fish passage in the region (ACIAR, 2017). For the Mekong River basin, the Mekong River Commission has also produced a guidelines document that includes fish passage requirements (Mekong River Commission, 2009). There is also sustainable developement agreements for the Mekong River (1995).

Japanese Huchen (Hucho perryi)

As the snow melts in spring, sexually mature huchen move upstream. Unlike some other salmon species, huchen don't die once they've reproduced, and can survive for 15 to 20 years.



In China there is an increasing interest in ecological restoration, river basin management and fish migration issues, as demonstrated by the translation of the European Fish Migration Guidance (Kroes, *et al.*, 2006) into a Chinese version (funded by the EU China River Basin Management Program) and ongoing basin level planning work with The Nature Conservancy for fish passage plans in the upper Yangtze River basin.

China

The legal framework supporting water management in China is centred on the Water Law of the Republic of China (2002), water-related laws on Environmental Impact Assessment and secondary legislation concerning regulation and related provisions (Yang & Griffiths, 2007). 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. Action is not yet truly integrated and implementation by the provinces is variable (Yang & Griffiths, 2007). More recently the Chinese interest in the EU Water Framework Directive has increased and China is now working on a River Health Assessment System (Griffiths & Torenbeek, 2011).

6.3.5 Africa

In Africa, there appears to be no specific legislation specific to fish migration on a continental level. There is one notable convention signed related to managing and conserving natural resources sustainably namely, the African Convention on the Conservation of Nature and Natural Resources (1968), signed in Algiers by 53 countries. The objectives of this convention are to enhance environmental protection, foster conservation and sustainable use of natural resources and to harmonize and coordinate policies in the view of achieving ecological sustainability.

In terms of legislation related to fish migration and river basin measures management, southern Africa appears to be forefront on both transboundary and national bases. In 1992, the Southern African Development Community (SADC) consisting of 14 sovereign states signed a treaty with the common goal of regional cooperation and integration on the basis of balance, equity and mutual benefit for all people in the region. The Treaty provides for member states to conclude a series of protocols that specify objectives, scope of and institutional mechanisms for cooperation and integration, which is an integral part of the Treaty. With the SADC Region, there are two protocols that aim to improve sustainability and conservation: a Revised Protocol on Shared Watercourses (2000) and the Protocol on Fisheries (2006). The Shared Watercourses protocol sets out an institutional framework necessary for effective implementation of the various provisions, including the establishment of River Basin Commissions (e.g. Orange-Sengu River Basin Commission, or ORASECOM), and elaborates on the objectives and specific functions of the proposed river basin management institutions.

There are also various legal frameworks focused toward protecting aquatic resources at a national level (FAO, 2018). In Zambia the protection and management of aquatic resources is fulfilled by the Environmental Management Act (EMA) (Act 12 of 2011), the Fisheries Act (No 22 of 2011),

EXAMPLE

The proposal for fish passage on the Gezhouba Dam and the Chinese Three Gorges Dam

Authors: Organisation:

Dr. Hui ZHANG¹ & Luhong WANG² (translation) ¹Yangtze Aquatic Research Institute, China Academy of Fisheries Science & ²The Nature Conservancy China Program China



INTRODUCTION

Closed in 1981, the Gezhouba Dam is the first dam in the mainstream of the Yangtze River. Historical regulations at that time resulted in no fish passage structures constructed on this dam. In 2002, construction of the China Three Gorges Dam started 40 kilometers upstream of the Gezhouba Dam and here, due to the huge water level difference, fish passage facilities were not constructed in this dam either. These two dams block the migration of fish in the Yangtze River.

WHAT DID YOU DO?

In August 2013, the National Development and Reform Commission launched research into a new navigation channel construction project on the Three Gorges Dam and a lock capacity improvement project on the Gezhouba Dam to promote transportation capacity of the Yangtze River. In this study, researchers also proposed a plan to build a fish passage system including multiple fish passage facilities along with the lock capacity improvement, and a new waterway construction to reconnect the river. In the meantime, the research also commended closure of Lock 1 of the Gezhouba Dam to create better spawning ground environments for anadromous species, such as the Chinese sturgeon (*Acipenser sinensis*).

HOW DID IT WORK OUT?

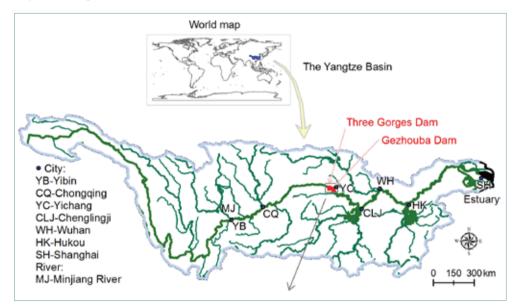
Although the proposal raises some controversy and is still under debate, it attracts more and more attention to the ecological importance of restoring connectivity for fish migration on the mainstream of the Yangtze River. Government agencies, research institutes companies and NGOs are now working together to conduct further research on feasible measures that can achieve this goal.

LESSONS LEARNED

The China Three Gorges Dam is currently the world's largest hydropower station, with a 100 meters water level difference. It is located only 40 kilometers upstream of the Gezhouba Dam. If this connectivity restoration project can be effectively implemented in the near future, it will not only benefit migratory fish in the Yangtze but also become a great example of how fish migration access can be reconnected in large rivers like the Yangtze.

FIGURE 1

Map of the Yangtze River Basin.



CONSTRUCTION OF THE TÅHREE GORGES DAM ON THE YANGTZE RIVER

The Three Gorges Dam in the Yangtze is the largest hydroelectric dam in the world. The dam stretches 2 km across the Yangtze River, creating a more than 600 km long reservoir. (Hubei Province, China) © Michel Gunther / WWF-Canon.



National Policy on Wetlands Conservation (2001), the Water Resources Management Act (No 21 of 2011), National Water Policy (1994) and the Zambia Wildlife Act (No. 12 of 1998).

Environmental legislation in South Africa provides for the protection and sustainable use of riverine ecosystems. When correctly and strictly applied should ensure appropriate provisions are made for the movement of aquatic biota when instream barriers are constructed. The enactment of National Water Act No. 36 of 1998 signalled a commitment to ecological and social sustainability. This Act recognises that water resources are part of a complex system with many users. It promotes protection of these resources so that people can use water both now and in the future (Palmer, et al., 2004). Specifically, Section 21 (c) and (i) of the NWA requires the licensing of any structures or activity that may impede or divert the flow, and/or alter the physical, chemical and/or biological characteristics of a watercourse which may impede the upstream and/or downstream migration of aquatic biota. Through the conditional approval for construction of instream barriers, this law can enforce the provision of fishways (Bok, et al., 2007).

The Act also mandates the establishment of catchment management agencies (CMA's) who are responsible for the water management in the 19 river basins in South Africa. The determination of the "Ecostatus" is one of the management tools.

Some other relevant acts in South Africa include the Environment Conservation Act, 1989 (No. 73 of 1989), National Environmental Management Act (No. 107 of 1998) and the National Environmental Management: Biodiversity Act (No. 10 of 2004).

In 1999 the 10 countries sharing the Nile watershed launched the Nile Basin Initiative for collaboration on social matters and maintaining peace, but it lead in 2008 to the signing of the Khartoum Declaration to include environmental policies and create a permanent Nile River Basin Commission. It does not specifically mention fish passage, but does have a component that focuses on water quality, flows, wetlands, and biodiversity. The World Bank holds a trust supported by member states, the US, several EU countries and Japan. see http://www.nilebasin.org.

There are also other conventions worth mentioning in Africa, including the Abidjan Convention (1981), the Convention on the Sustainable Management of Lake Tanganyika (2003) and the East African Community (1999) Niger Basin Water Chater (2008) and the Okavango River Basin Water Commission (OKACOM) agreement (1994).

Regions of transboundary management in southern Africa

A) Confluence of the Kabompo and Zambezi river, Barotse Floodplain, Zambia. © Annemarie Winkelhagen/WWF. B) The lower Oranje River on the South African - Namibian border. © Wilco de Bruijne.





Bull shark (Carcharhinus leucas)

The Bull shark is one of the few shark species that can tolerate long periods of time in freshwater, often migrating long distances up rivers that connect to the sea.



6.3.6 Australia

Fish passage is regulated across Australia by a range of legislation, policies and guidelines. At the national level, fish passage is broadly regulated within environmental protection legislation and is only enacted when threatened species are affected by the development. Generally, the implementation of specific fish passage legislation is provided by each of the individual states, usually within the states and territories Fisheries acts. However, across Australia there is a wide variation in the level of implementation of fish passage at a state level; some states have detailed legislation, policy and guidelines, while others have little or no reference to fish passage in their legislation.

This results in a wide difference in implementation of fish passage regulation and implementation in each of the states, with Queensland, New South Wales and Victoria having extensive fish passage programs administered by state fisheries, while the other states have minimal fish passage programs that have seen the effective development of few fishways (Table 6.2). This summary of the legislation and policy across the state of Australia relating to fish passage indicates the potential complexity of governance systems to ensure fish migration is protected. While fish passage from an ecological perspective is equally important in these other states, the strong focus on research (and hence policy development) in the eastern states, has seen these jurisdictions develop robust fish passage policies and related legislation that have benefited their fisheries greatly.

In Queensland when waterway barrier works (instream structures) are installed across waterways, even as partial barriers, they are regulated under the Queensland Fisheries Act 1994 and the new Queensland Planning Act 2016. The planning act stipulates approval processes for waterway barrier works while the principles of ecologically sustainable fisheries development are enshrined in the Fisheries Act and compliance is enforceable under the Fisheries Act. Broad-scale regulation across Queenland is enabled through robus codes for accepted development (self-assessable) of a state-wide GIS waterways layer. This layer is used for risk rating barriers, design processes and for criteria for fishways.

Increasing the research and development of fish passage in states with little current legislation will will highligh the need for strong fish passage legislation in these states.

Table 6.2 Summary of the legislation and policy across the states of Australia relating to fish passage

Northern territory	Section 14 of the Northern Territory fisheries regulations caters for the impeding of	
	passage of fish or aquatic life.	
	Water Act 1992, prevents structures affecting flow within a waterway and is only limited	
	to larger structures such as construction of a dam.	
Queensland	Fisheries Act 1994, defines waterway barrier works and identifies fisheries development	
	(including waterway barrier works). The Act sets out the principles for ecologically	
	sustainable fisheries development which are the foundation for policies and codes used in	
	development assessment.	
	Planning Act 2016, provides the framework for application for and assessment of fisheries	
	development approvals, including streamlined development processes for certain waterway	
	barrier works that are identified as accepted development (i.e self-assessable).	
South Australia	Fisheries Management Act (2007), with no provision for fish passage at a barrier, this	
	Act does provide conservation and management of aquatic resources, including fisheries,	
	reserves, regulation of fishing, and protection of aquatic resources.	
	Informal recognition is growing over the need to provide fish passage at new	
	infrastructure. It is now commonly considered during the development stages although	
	not mandated	
New South Wales	Fisheries Management Act (1994), provisions to ensure the maintenance and restoration	
	of fish passage as part of the construction or modification of instream structures.	
	Water Management Act 2000, construction, which impacts on flows within waterways	
	may also be "controlled activities" for the purposes of the act.	
Victoria	Water Act 1989 stipulates that works on waterways such as the construction of dams,	
	weirs and erosion control structures should be licensed.	
	The Convention, forests and Lands Act 1987 requires public authorities to submit	
	work plans for projects potentially interfering with movement of fish or aquatic habitat	
	quality.	
	The Flora and Fauna Guarantee Act 1988 provides protection of fish passage.	
	Prevention of passage of aquatic biota as a result of instream structures' is a potentially	
	threatening process and 'there should be no futher preventable declines in the viablity of	
	any rare species'.	
	Fisheries Act 1995 provides protection of aquatic habitat through two provisions relating	
	to maintaining fish habitat and protection of specific fish species.	
	Environment Effects Act 1978 may also trigger relevant fish passage issues during local	
	planning applications.	
	Victorian Waterway Management Strategy (DEPI 2013) states that passage for native	
	fish in waterways will be maintained or improved by minimising further loss of connectivity	
	and improving fish passage at priority sites.	
Western Australia	Western Australian Fish Resources Management Act (1994) is the principal Act	
	regulating the management of, and utilisation and conservation of fish (which includes all	
	aquatic organisms except reptiles, birds, mammals, amphibians) and their habitats.	
Tasmania	Inland Fisheries Act (1995) includes provisions to ensure the maintenance of free	
	passage of fish under Sections 139, 158 and 160.	
Australian capital	The Water Resources Act (2000) contains the only provisions for the protection of fish	
Territory	passage, in sections 41 to 46.	

On a national scale, the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) establishes a system of environmental assessment and approval by the Australian Government for actions that significantly affect matters of national environmental significance.

The Australian and some state governments have signed bilateral agreements which allows the assessment regimes under the state agencies to be automatically accredited under the EPBC Act. This means that separate assessment processes are not required. The bilateral agreement only covers matters that are determined to be 'controlled actions' by the Australian Government. If a proposal is likely to have an impact upon any 'Matter of National Environmental Significance' under the EPBC Act, such as:

- · Heritage values of World Heritage properties;
- · Listed National Heritage places;
- Wetlands of international importance (Ramsar wetlands);
- Commonwealth-listed threatened species and ecological communities;
- · Listed migratory species.

Then the proponent has an obligation under the EPBC Act to refer the proposal to the Commonwealth Environment Minister for a decision as to whether the action is a 'controlled action' and therefore requires assessment and approval via a bilateral agreement. Third parties may also refer potential controlled actions to the Minister.

Shortfin eel (Anguilla australis)

This species is gender neutral up tot a lenght of ca. 20 cm. Afer reaching this size the indivuduals become male or female.



Russian sturgeon (Acipenser gueldenstaedtii)

The Russian sturgeon is found mainly in the countries surrounding the Black Sea. The adults migrate up the rivers to spawn every 2-6 years, throughout their entire life.



6.3.7 Russia

Legislative policy in Russia provides protection of migratory fish. For this purpose, dams blocking the routes of migrating fish must be equipped with fish passage facilities, and water intakes should be equipped with fish protection devices.

These requirements are contained in a few acts, including:

- Federal Law no. 166-FZ of 20 December 2004
 "On Fishery and Conservation of Aquatic Biological Resources";
- Water code of the Russian Federation no. 74-FZ of 3 June 2006;
- Decree of the RF Government no. 380 of 29 April 2013 "On approval of the Regulations on measures for conservation of aquatic biological resources and their habitats".

In addition to this, a set of construction norms and rules (CN) is used in Russia, including CN 101.133 30.2012, which specifies that "Retaining walls, shipping locks, fish ladders and fish protection structures" should be considered. This is the updated version of SNiP 2.06.07.87.

QUEENSLAND WATERWAYS FOR WATERWAY BARRIER WORKS

Tim Marsden, Australasian Fish Passage Service (Australia)

The Fisheries Act in Australia has a broad definition of waterways, making it difficult to regulate "water barrier works" such as construction, raising, replacement and some maintenance works on both permanent and temporary structures such as culverts, bed level and low level crossings, bridges, weirs and dams. In Queensland, water managers developed a data layer to delineate and prioritize these waterways in order to more efficiently regulate instream barriers under the national *Fisheries Act 1994* and the *Planning Act 2016*.

Figure: Mapping of Queensland waterway barrier works streams.

The layer depicts the risk associated with development (low to major) in or around every stream in Queensland as a coloured stream network from the upstream limit, downstream to the tidal or wetland conclusion.



This mapping accompanied the release of updated development codes in 2013 that were revised in 2017 to form the Department of Aquaculture and Fisheries' (DAF's) Accepted Development Requirements to coincide with the new Queensland Planning Act. The Planning Act provides streamlined development processes for certain waterway barrier work identified as accepted developments. Work that complies with Fisheries Queensland' requirements are able to proceed without development approval.

The State Development Assessment Provisions includes generic design criteria for possible fish passage scenarios, including development involving bridges, culverts, bed level crossings, fishways, floodgates, and temporary barriers. The Environmental Offsets Act 2014 describes requirements for projects which result in impacts to fish passage, that cannot be avoided or mitigated on-site. Offsets may include providing, or funding, remediation of fish passage at identified waterway barriers as part of proponent driven offset projects.

6.4 NATIONAL AND REGIONAL POLICIES

Generally, each country has its own legislation, policies and agreements related to river basin and fisheries management. The competence of each to deliver required outcomes for the protection of fish migration and fish stocks varies greatly. Sharing best practice more effectively across countries could lead to the development of more protective provisions to protect fish migration globally.

There has been a widescale focus on protecting fish migration in Europe and the USA for many years (more than 100 in some instances), but generally this was for salmonids only. In Europe this was only expanded to other species during the latter half of the 20th century, with a few notable exceptions. Elsewhere around the world fish passage has only more recently received the attention it deserves but has now been more widely incorporated into national and state legislations and regulations (Katopodis & Williams, 2012).

Most of the research and efforts toward development of technical and policy specifically relating to the tackling of fish migration issues has primarily been in the USA, Europe and Australia.

In countries where policy is not as well-developed, federal and national laws have increasingly been created and implemented to promote fishways, dam removals, habitat restoration, river basin managment and other measures that aim to recover migratory fish stocks. Where this has not yet happened, we recommend greater attention shoud be committed to this to ensure important fish resources are adequately protected.

6.5 IMPLEMENTING CONVENTIONS, LAWS AND POLICY

As a global community, we are getting better at securing and implementing the national, transboundary and international agreements needed to secure positive outcomes for migratory fish. A regulatory and enforcement approach may be needed to ensure that states deliver on their obligations and commitments to rivers. There is also a clear place and role for international lobby groups and NGOs to maintain pressure on governments to deliver.

Legal provisions alone do not always result in the desired outcomes for migratory fish populations and habitats. This is demonstrated by the continued deterioration of fish populations in most countries around the world.

The success of legislation is dependent on a myriad of factors relating to the extent of governance, enforcement, implementation, financial support, conflicts, awareness, specific focus of legal frameworks and so on. Developing countries often have difficulties in enforcing regulations due to a lack of resources, limited financial support, lack of political will because fish and river protection is often afforded low priority, and for jurisdictional issues and in some cases corruption. This is worse in countries that have no formal legal mechanisms specific to river and fish protections. Even when fish protections are included in policies, the objectives are sometimes highly abstract, leading to a decoupling from the required policy cycle that translates into implementation of measures.

Added to this is the intense pressure to continue to develop large-scale hydropower and water storage and diversion projects. Many organisations and institutions are now working together with governments, communities, funders and companies to ensure that developments can meet energy and water needs of countries while maintaining healthy rivers (Moir, *et al.*, 2012).

There are numerous mechanisms that can be used as leverage to protect rivers through legal and a combination of other means. Moir, *et al.* (2012) distinguished between five river-based protection mechanisms, which can be used by various stakeholders to implement legislation that protects rivers, including linkages to:

SPECIES EXAMPLE

Ecology of "dourado" *Salminus brasiliensis* (Cuvier 1816): the "king of the river"

Authors:

Anielly Galego de Oliveira, Mirtha Amanda Angulo Valencia, Rafaela Giacomel Rauber, Rosa Maria Dias & Angelo Antonio Agostinho State University of Maringá Brazil

Organisation: Country:

INTRODUCTION

The "dourado" *Salminus brasiliensis*, is a potamodromous fish which performs long reproductive migrations (up to 1000 km) within their home rivers. Its distribution includes the Paraná, Paraguay and Uruguay basins, and also the Laguna dos Patos drainage, and the upper Chaparé and Mamoré River basins in Bolivia. The species attains a length of up to 100 cm and is highly prized by sport and commercial fishermen. *S. brasiliensis* is a top predator, feeding mainly on fish (Agostinho *et al.*, 2003).

LIFE-CYCLE

The "dourado" demands critical habitats for breeding, initial fry development, growth and feeding. The onset of migration and spawning are stimulated by increasing water temperature, seasonal precipitation and consequent flooding and advancing sexual maturation. Shoals migrate upstream towards the river's headwaters and tributaries, where spawning occurs. The eggs passively drift downstream while they develop

SALMINUS BRASILIENSIS (Cuvier 1816) Dourado ©Nupelia-UEM.



and hatch, with the resulting larvae continuing to drift until they almost deplete the yolk reserves, then displacing to the recently flooded areas for initial feeding and growth. There is no parental care, and the offspring benefit from turbid waters and comparatively few predators. After the reproductive upstream migration, adults return to their downstream feeding sites. As the seasonal floods subside the young leave the lagoons to inhabit the main channel of the rivers (Suzuki *et al.*, 2009).

HUMAN IMPACTS

The main threat to migratory fish such as *S. brasiliensis* is the proliferation of dams, mainly for hydroelectric development. Besides altering the dynamics of the river and the natural flooding pulse, dams block migratory connectivity between critical habitats (i.e. spawning and nurseries) and affect the triggering of reproduction events and recruitment success. The increasing rarity of this species in the fisheries located in those basins with reservoir developments, such as the upper Paraná and Uruguay rivers, corroborates this impact (Agostinho *et al.*, 2007).

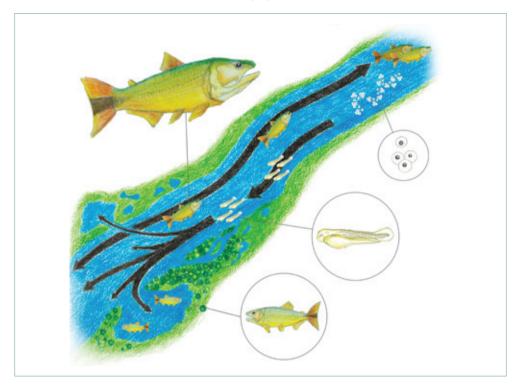
POSSIBLE SOLUTIONS

Among the alternatives to mitigate the impacts on dourado reproduction, key initiatives stands out:

 Releases of water from impoundments, simulating the natural flood. Releases must be made to ensure the minimum requirements of

REPRODUCTION CYCLE OF THE DOURADO

© Ana Leticia Rauber and Gabriel de Carvalho Deprá).



the species for successful migration, spawning and offspring survival (Oliveira *et al.*, 2015);

 the maintenance of some tributaries, large enough to include spawning and nurseries area, keeping them free from dams and protected against deforestation and pollution (Affonso *et al.*, 2015).

LOOK TO THE FUTURE

The main actions needed to preserve viable populations of *S.brasiliensis* are:

 It is important to preserve some large tributaries that contain all habitats necessary for the dourado to complete its life cycle. The species requires a distance of at least 50 km between the spawning and nursery areas, in which the eggs and the initial larvae drift and develop until the external feeding phase. Such tributaries should be conserved with no dams permitted;

- In rivers that are already dammed, flow management is required to protect natural hydrological flows, perhaps through reservoir releases. Successful recruitment is highly dependent on flood attributes such as timing, duration and intensity of events;
- There should be prohibitions of fishing during the reproductive season to ensure sufficient spawning escapement. Fishery closure measures should be enforced to protect the vulnerable breeding stock.

The protection of the large home range and habitat requirements of the 'umbrella species' dourado would mean that many other species would also benefit.

- Protected areas: Clearly defined geographical spaces dedicated and managed through legal or other effective means;
- Designated rivers or river segments: to prevent development and preserve outstanding natural values;
- Environmental water reserve: volumes of water allocated for environmental use to enhance long-term sustainability and support more natural flows;
- **Biodiversity offset**: compensating for biodiversity impacts in one area in exchange for the protection of another area;
- Species-specific reserve: spatially defined area based on a specific species. In the case of freshwater systems, these reserves are usually targeted toward fish species to increase natural fish stocks;
- Water Basin scale planning: identifying and designating areas (sub-basins) within a larger river basin ineligible for licensing for new dams to protect environmental and cultural values.

6.6 GENERAL CONCLUSIONS

Effective fish migration policy and legislation is more developed in Europe, North America and Australia where there is the longest history of river damming, diversion, and development. This is where the most environmental damage and species loss has occurred over the past two centuries. However, many other regions of the world are rapidly developing effective regulations, notably Asia, Russia and South America. All stand to learn from places where hard-won advances in protection and hugely expensive restoration has been occurring.

It is vital to ensure that commitments made, are delivered if fish stocks and fisheries are to be protected by addressing declines and promoting recovery. In this regard, investigations or 'quality audits' at catchment, national, and sometimes continental scales would highlight areas with current and projected future declines, but also important successes. In this way we will learn if and how society is restoring and protecting these important resources at the pace, scale and quality needed to stave off permanent losses.

The regions with the greatest risk of imminent habitat fragmentation, from proposed large and extensive hydropower developments, are in Asia, Africa and South America. Effective policy and legislation is needed in these regions if vital fisheries resources and ecosystem health is to be protected. There needs to be provision for protecting fish migrations and impending range expansions especially as our climates changes and rivers and their residents adjust.

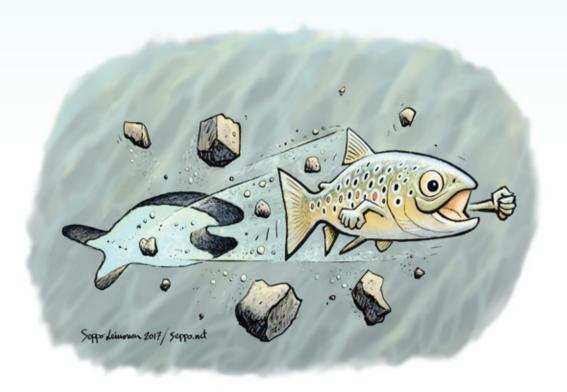
CHAPTER 7 DAM REMOVAL

The 64 m high Glines Canyon Dam (also known as Upper Elwha Dam) during removal. © US National Park Service.

INTRO

Removing barriers to restore fish passage and connectivity has many positive long-term and sustainable benefits to river fish and wildlife, stream processes, and the surrounding natural and human ecosystems (King, et al., 2017; Poff & Hart, 2002; Garcia de Leaniz, 2008). From a fish passage perspective, it allows migrating species to recolonize or de-populated reaches of the river and contribute to the broader restoration of riverine processes. This is most well-recognized for the large and well-known species, such as salmon, alewife and eel, but is just as important for lesser-known but often ecologically important weaker swimming fish and non-target species, which find it difficult to pass fishways and other restorative measures.

In the dam removal decision-making process, there are many political, social, economic and environmental factors that all play an important role and must be considered. In the USA, while many projects are initiated for the purpose of restoring fish passage and connectivity, often it is the dam safety and economic factors that play a deciding role in the final barriers that get removed (Graber & McClain, 2012). In Europe and Australia, river restoration seems to be the principal incentive for dam removals in recent years.



7.1 DAM REMOVAL OVERVIEW

There are many different solutions for achieving improved fish passage. Perhaps one of the most effective, but often controversial, solution to improving fish passage is the removal of instream barriers such as weirs and dams. Although dam removal may be assumed to be a new mitigation measure, communities have been removing dams for almost as long as they have been building them (Wildman, 2013). Dams are removed for many different reasons. Removal can be for the construction of a new replacement dam, eliminating upstream flooding of private lands or mitigating blocked fish runs. It can also be for restoring water rights, eliminating dam safety concerns, reducing maintenance costs, or simply because the dam no longer serves its original purpose or is no longer economically viable (Wildman, 2013; Bellmore, et al., 2016). From the early 1990's, the rehabilitation of rivers to improve connectivity and ecological functioning became a key driver (together with dam safety and economic concerns) for dam removal (Foley, et al., 2017; Lejon, et al., 2009). This has resulted in thousands of dams being removed in several regions around the world, notably in the USA and more recently in Europe. These completed projects have improved our understanding of the processes associated with dam removal and their effect on river and ecosystem connectivity.

Within the larger river management context, our global reliance on dams for irrigation, hydropower, flood control and water supply means that not all instream barriers can be removed. Dam managers must therefore make more informed provisions for fish passage through better catchment planning of barriers. Recognition of this strategy, has led to the steady growth over the last 15 years of more technical and informed approaches to prioritizing and optimizing fish passage and barrier removal efforts for better economic, ecological, and social outcomes (Silva, et al., 2017). More can be done to improve management and access to information for decision-making by making models more accessible, biologically relevant and user friendly to river managers. Some key barrier assessments and prioritization approach methods have been reviewed by O'Hanley *et al.* (2013) and Kemp & O'Hanley (2010). These authors highlighted the disadvantages of scoring-and-ranking type methods and promoted their own approaches that consider cumulative benefits of multi-barrier repairs/removal, and more robust optimization models. Scoring and ranking methods are, however, shown by others to be advantageous. King, *et al.* (2017) provide a modelling approach to help river managers decide on a course of action that can help to allocate limited resources to restoration of connectivity and maximization of ecological improvements.

7.1.1 Global trends

Although most of the dam removals have been documented in the USA and Europe, there is a growing interest globally. This is particularly evident in Australia and Asia, where there are more and more cases of dam removal and reports showing the benefits of dam removal within ecological restoration programmes (Beatty, *et al.*, 2017; Pittock & Hartmann, 2011).

Here we review some of the most notable dam removals around the world.

USA

In the USA, dam removals have been well reviewed and documented (Bellmore, et al., 2016; Hart, et al., 2002; Bednarek, 2001; Foley, et al., 2017; Heinz Center, 2002; Stanley & Doyle, 2003). Since 1999 the non-profit organisation, American Rivers, collects data annually on dam removals and makes it freely available online (American Rivers, 2017). This nationwide inventory reveals that 1,489 dams were removed from rivers in the USA from 1916 through to 2017 (Figure 7.1). This includes 86 dams in 2017 alone, and the removal of the tallest dam ever removed in the USA: the Glines Canvon Dam on Washington's Elwha River (64 m). The focus of most published data is on larger dam removals such as the Glines Canyon Dam, whereas studies of smaller barriers are few in comparison (Bellmore, et al., 2016; Wippelhauser, et al., 2014; Hogg, et al., 2015; Catalano, et al., 2007).

EXAMPLE

Penobscot River Restoration Project

Author: Organisation: Country: Joshua Royte The Nature Conservancy USA



INTRODUCTION

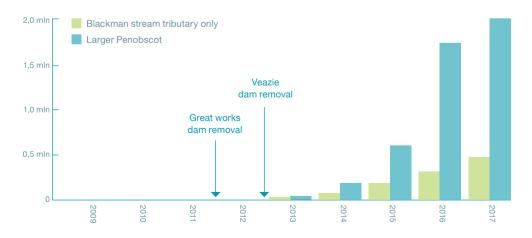
The Penobscot River, Maine is the most promising place in the USA for restoring endangered Atlantic salmon and 11 other searun fishes. Historically 100,000 salmon, 3-5 million American shad, and 20 million river herring ran upriver yearly (Hall, 2011). Their offspring provided forage for river and marine fish, birds, mammals, and a worldclass cod, hake and halibut fishery (Lichter, 2012). It all nearly ended after dam building started in the 1820's along with log-driving and severe pollution. The Penobscot River Restoration Project provided a chance to restore the river's ecology and economy.

WHAT DID YOU DO?

The Penobscot Indian Nation petitioned governments for over 200 years to restore treatise rights to harvest migratory fish. But it took until 2004 for politics, dam and energy regulations, tribal rights and the contentious failure of a nearby dam proposal to set the stage for a glo-

FIGURE 1

Recovery of river herring runs Blackman stream portion and total measured Penobscot river.



PENOBSCOT VEAZIE DAM BEFORE AND AFTER REMOVAL IN 2013





bally significant compromise; the Penobscot Settlement Accord. This allowed 6 NGO's and the Penobscot Nation to purchase three mainstem hydro dams, remove the two lowermost, and bypass the third upstream, while fish passage was improved at 3 other dams, and hydro capacity increased at 6 other dams (Opperman, 2011). For a company facing aging dam maintenance, new fish passage, and <18 Mw produced by the project's 3 dams combined this was a good solution.

In June 2012, Penobscot Nation members welcomed senators, representatives from Federal and state fisheries agencies, global and local non-profits and community members to witness the demolition of the Great Works Dam. A year later Veazie Dam was removed and a new fish lift was opened at Milford Dam. In 2016, the decommissioned Howland Dam was bypassed with a nature-like channel. The project restored the free-flowing lower river for Atlantic and shortnose sturgeon, rainbow smelt, tomcod, and striped bass, and access to over 3,200 km of habitat for salmon, American eel, searun brook trout, sea lamprey, river herring, and shad.

HOW DID IT WORK OUT?

Energy production increased and all 12 species have been documented using the restored habitat. Salmon recovery is slow, but river herring numbers grew from a few 100 to nearly 2 million fish and shad from 11 to 8,000 fish by the spring of 2017. River banks have revegetated and people from around the world attended 3 years of paddling competitions for the Whitewater National Regatta. Fishing for shad and river herring harvests has resumed. Herring are used as bait for Maine's iconic lobster fishery and studies will measure the impact of restored billions of juvenile fish on marine fisheries.

LESSONS LEARNED

Success for river restoration projects depends on our ability to develop and sustain relationships between people representing diverse interests that bring the creative capacity to meld ecology, hydrology, energy production, cultural needs and finances. In this case federal rules allowed consideration of multiple dams at once and required consideration of tribal and ecological values. The Penobscot is a model for balancing hydropower with human and ecosystems for rivers and the sea.

ADVANCING DAM REMOVAL IN THE UNITED STATES Bob Irvin (President, American Rivers, USA)

The restoration of fish species and their migrations can be a compelling driver for dam removal and river restoration. Across the United States, American Rivers has successfully removed dams to open access to historic habitat and restore river health, revitalizing endangered fish populations.

In 1999, we were instrumental in the removal of Edwards Dam on Maine's Kennebec River. A decade later, more than two million alewives returned to the Kennebec, the largest migration of its kind on the eastern seaboard. On the west coast, removal of two dams on the Elwha River in 2011 was triggered by the need to restore runs of endangered salmon. The first season after Elwha Dam fell, more than 200 spawning chinook salmon were counted above the former dam site. Today, fish populations in the Elwha are the highest in 30 years.

More than 1,400 dams of all sizes have been removed across the United States, and the momentum is growing, spurred by community interest to restore fish and wildlife, water quality and public safety. American Rivers is working strategically to advance dam removal projects that will have the biggest benefit for endangered fish and wildlife, including seeking opportunities to remove multiple dams in a single river or watershed. As we have seen on the Kennebec, Elwha, and many rivers nationwide, the fish will come back, if we just give them a chance.

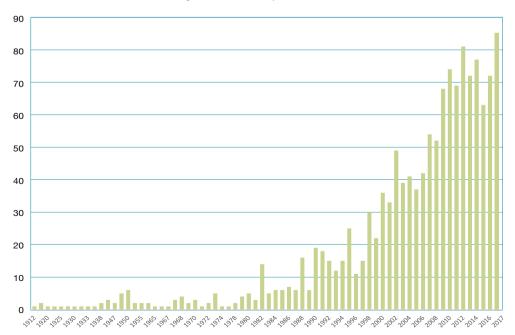


Figure 7.1 Annual number of dams removed in the USA from 1912 to 2017

Data Source: www.americanrivers.org/damremovalsmap

Europe

There are thousands of documented examples of dam removals specifically to resolve fish passage issues in the UUK (some even dating back to the 16th century), Sweden, Spain and France (Dam Removal Europe, 2016; Garcia de Leaniz, 2008; Sneddon, *et al.*, 2017). Data on these removals, many summarized in Table 7.1, are currently being compiled by the Dam Removal Europe project and based on information collated and mapped from various national institutions.

In Sweden, the national Swedish database indicates that there have been over 1,600 dams and barriers removed. Although it is only in recent years that barriers have been considered for removal specifically to restore stream connectivity (Lejon, *et al.*, 2009). One of the largest freshwater projects in Sweden was the REMIBAR (Remediation of Migratory Barriers in Streams) EU LIFE+ project, which was in place between 2011 and 2016. During this project over 300 barriers in five drainage basins have been remediated. This was intended to resolve poorly located and designed culverts that significantly impacted species such as the Atlantic salmon brown trout and even otters.

The number of dam removals in France are well documented. It is estimated that there are over 2,400 fully removed obstacles and 5,900 partially removed obstacles (Sandre, Eau France, 2017). These numbers are based on both planned barrier removals as well as barriers that have been destroyed naturally due to dam failures (storm, flooding, etc). As a result it is difficult to identify the exact numbers of planned dam removals for river restoration.

According to Germaine & Lespez (2017), most of the planned dam removals are relatively small such as the the Maisons-Rouges Dam (4 m). There are also numerous large dam removals in France that are not to be discounted, including the Saint-Étienne du Vigan Dam (12 m), removed in 1998, and Kernansquillec Dam (15 m) (Epple, 2016). In 2017, the French minister confirmed the future removal of the Vezin Dam (35 m) and

The La Gotera Dam removal, before and after

In September 2011 the Duero Basin Authority removed the La Gotera Dam, located in the Bernesga River (León, Spain). This project is part of the Spanish National Strategy of River Restoration, whose objective is restoration of channel continuity in a significant reach of this emblematic river flowing through the Alto Bernesga Biosphere Reserve of the Man. Monitoring of the project included channel evolution, when the river mobilized 90 years of accumulated sediments. © Herman Wanningen.



Roche qui boit Dam (16 m), which will be two of the largest dam removals in France.

In other European countries, the number of documented dam removals is considerably lower. In Spain, there have been more than 200 dam removals, mostly in the Basque Country within the Navarro and Duero River basins (Garcia de Leaniz, 2008). In the UK, around 140 weirs and barriers were documented to have been removed between 1983 and 2013, although this is a considerable underestimate.

In a recent Webinar, the World Fish Migration Foundation discussed dam removal in terms

Table 7.1 Estimated dam removals in various countries across Europe

(Dam Removal Europe, 2016 and 2017).

Country	Number of known dam removals for river restoration	Source of data
UK	>140	Environment Agency (EA) and Natural Resources Wales, with partners, from between 1983-2013.
		Probably an under-estimate
France	>3,000	French Agency of Biodiversity (AFB) and Eaufrance
Sweden	1,600 approximately	National Swedish Database
Finland	>450	Finnish Environment Institute (SYKE)
Spain	>200	Ministry of Environment of Spain (MAPAMA)

of dam ownership, social drivers, legislation, management, authorization, payments, grants and costs for removals in various countries across Europe (Dam Removal Europe, 2017). Table 7.1 summarizes some of the details discussed in the webinar and cited the Dam Removal Europe project.

Australia

The decision to remove dams in Australia has been motivated by financial as well as environmental reasons. An extensive review of the status of dam removal in Australia within the different states (Beat-ty, et al., 2013) has shown that New South Wales (NSW) authorities were the amound of the most active in removing redundant barriers. Since the 1990's governmental departments have investigated the impacts of instream barriers to habitat and fish passage. This laid the foundation for prioritisation of thousands of weir structures, assessments of impacts from road crossings and various other instream barriers. Which has ultimately culminated in the remediation of over 200 sites, increasing the accessible habitat by 16,000 km. In 2011 they introduced the "Fish Superhighways" programme which has led to the remediation of 73 barriers through removal and installation of numerous fishways, including partial-width rock-ramps, full-width rockramps and vertical slot fishways (State Water New South Wales, 2017). The NSW Department of Primary Industries (Fisheries) has a complete database available (Mathew Gordos, 2017, pers. comm.).

Asia

As in most other areas around the world, Asian rivers are fragmented by a myriad of dams and tens of thousands of weirs. In South Korea, it was noted that there are about 18,000 weirs, some of which have lost their original irrigation function since many of the paddy lands have been converted into urban areas (Woo, 2010). As a result, river restoration projects have been researched and dam removal has evolved into a recognised solution. For example, a weir was removed in the River Gokreung in order to restore an aquatic ecocorridor for migratory eels (Ahn, *et al.*, 2008).

The Arase Dam (25 m height and 210 m width) on the Kuma River was the first major dam to be removed in Japan in 2014. This removal received much attention by both the press and researchers due to the size and extent of the project (Fukuaoka, *et al.*, 2013).

In Taiwan, the Chijiawan River Dam, a tributary to the Tachia River in the Shi-Pa National Park, was the first known dam to be removed in this country for environmental reasons. The dam was removed in 2011 for safety concerns, but significantly increased accessible habitat for the endemic landlocked Formosan salmon (*Oncorhynchus masouformosanus*) (Wang, *et al.*, 2014), not known to occur anywhere else.

In China, dams have played a central role

in the socio-economic development of the country since the 1970's. This resulted in most rivers being regulated and the construction of the largest dams in the world including the Three Gorges Dam. In major systems such as the Yangtze River, the Yellow River and the Mekong River, the series of large scale dam developments has resulted in severe negative impacts to biodiversity (e.g. the loss of one of the world's freshwater dolphins), ecosystem degradation, hydrologic alteration, and largescale displacement of human populations and cultural resources. As a consequence, local environmentalists and NGO's have started to focus efforts on their national dam construction policy and working more closely with water ministries and dam development agencies.

Local authorities are increasingly aware of these issues, and are working with many partners to develop mitigating strategies, while still focusing on construction for hydrological risk mitigation, energy security and to reduce carbon emissions in the region (Miao, *et al.*, 2015).

South America

The Chinese experience is being replicated in Brazil and other South American countries where dam development continues at a very high rate (Zarfl, *et al.*, 2015). Since the 1960's the Brazilian government has recognised the impacts of dams and has introduced legislation intended to mitigate these impacts and to protect migratory fish. The focus has largely been on fishways, and the necessary underpinning legislation in two states (Section 6.3.2).

Siamese giant carp

The Siamese giant carp, or giant barb, is another species that benefits from free-flowing, undammed rivers because it needs to migrate between the main river, smaller tributaries, floodplains and flooded forests to feed, rest and spawn. Tonlé Sap river, Cambodia. © Zeb Hogan.



EXAMPLE

The first example of dam removal in Japan: Removal of the Arase Dam is almost complete

Author: Organisation:

Country:

Shoko Tsuru Association to Revive the rich Kumagawa River Japan



INTRODUCTION

Arase Dam is a large dam built in 1954 on the Kumagawa River, a 116 km long river which runs through the southern part of Kumamoto Prefecture. Arase Dam was built as a hydroelectric power generation dam, with a height of 25 m, and a length of 210.8 m.

Three dams were built on the mainstream of the Kuma River in the 1950's, and since then residents of the watershed and the Yatushirokai seashore have been plagued by increased flooding, deterioration of the environment, and a reduction in the fish catch.

The prospect for construction of another large multipurpose dam in a tributary of the Kuma River was raised, and a residents movement against this new dam and for the removal of the Arase Dam spread in the watershed.

As a result, it was decided that removal of the Arase Dam and cancellation of the Kawabe River dam plan should proceed, and work to remove Arase Dam started in 2012.

The removal work has now been nearly comple-

ted, and the flow of the river has almost returned after 60 years. Also, sand has started to return to the tidal flats of the estuary which had become muddy flats after dam construction, and the sea fauna has also been increasing.

WHAT DID WE DO?

We held many meetings and study sessions in order to help watershed residents understand the problems associated with the dam. We also repeatedly submitted requests and protests to the prefectural assembly and the Ministry of Land, Infrastructure and Transport.

We also conducted an environmental survey of the watersheds and tidal flats producing midrange forecasts that predicted the outcomes of dam construction, and used this in negotiations with business operators.

Farmers who are beneficiaries of the dam and fishermen who have the fishing rights on the Kumagawa river have each filed a number of lawsuits. Many groups opposing the dam were established inside and outside the prefecture, and the campaign against the dam expanded both inside and outside the prefecture.

HOW DID IT WORK OUT?

Public opinion opposing the dams increased steadily, and the prefectural governor officially announced the removal of the Arase Dam and the cancellation of the Kawabegawa Dam construction in 2010. The removal works of the Arase Dam as planned was to last for 6 years it began on April 1, 2012, and it is now almost complete.

We can now see the flowing river with rapids and pools where the dam used to be and, in particular, many living things have already come back to tributaries and the tidal flats.

LESSONS LEARNED

Regardless of the size of the river, it is obvious that any dam which stops the flow of the river will cause great damage to living creatures and the lives of residents. Construction of the Arase dam brought considerable environmental damage, but no clear benefits for society.

It is time to think seriously what we should leave for the future, either a free-flowing river that gives good and sustainable blessings forever, or a concrete dam that does not.

ARASE DAM BEFORE (2009) AND AFTER (2018) REMOVAL

A) The removal of the Arase dam started in 2012 and B) The removal activities have finished in 2018.





EXAMPLE

Best practice passage solutions improve upstream and downstream passage of Atlantic salmon

Authors:

Country:

Nyqvist, D.¹, Nilsson, P.A.^{1,2}, Alenäs, I.³, Elghagen, J.^{1,4}, Hebrand, M.⁵, Karlsson, S^{1,6}, Kläppe, S.⁵ & Calles, O.¹

Organisation:

¹Karlstad University, ²Lund University, ³Falkenberg Energi, ⁴Elghagen Fiskevård, ⁵Fiskevårdsteknik AB & ⁶SLU Aqua Sweden



INTRODUCTION

In rivers, fish may migrate to feed, reproduce or to seek refuge. The need to enable two-way passage for fish at migration obstacles has been long acknowledged but despite this, fish passage solutions have focused mainly on the upstream passage of strong swimmers such as large salmonids. During the last few decades however, nature-like fishways, for upstreamand downstream migrating fish, as well as more technical downstream passage solutions have been widely promoted (Calles *et al.*, 2013; Montgomery 2004, Nyqvist *et al.*, 2016).

RIVER ÄTRAN, SWEDEN

The nature-like fishway at the Herting hydropower plant, River Ätran, Sweden. © Fiskevårdsteknik AB.



WHAT DID YOU DO?

At Herting hydropower dam in southern Sweden, a technical fishway for upstream migrating salmonids, and a simple bypass entrance/trash gate for downstream migrating fish were replaced by a large nature-like fishway for up- and downstream migrating fish, and a low-sloping rack, guiding downstream migrating fish to the bypass entrance.

We evaluated these remedial measures for adult Atlantic salmon spawners and kelts, in a before/ after radio telemetry study (Nyqvist *et al.*, 2017). We studied passage efficiencies - the percentage of fish successfully passing the dam from the number of fish trying to pass - and the delay experienced. We also studied how passage rate - the proportion of fish passing over time - was affected by the remedial measures, and by fish characteristics and environmental conditions (Castro-Santos & Perry 2012).

HOW DID IT WORK OUT?

Upstream passage

Overall passage efficiency increased from 70% through the Denil fishway, to 97% through the nature-like fishway. Time from release to passage was also reduced. Before the remedial

measures the upstream migrating fish took on average 3 weeks to pass, whereas they passed on average in 4 days through the nature-like fishway.

Before modifications, upstream passage rate through the technical fishway was higher at elevated temperatures, at day compared to night, and for males compared to females. No such effects were observed for the nature-like fishway, indicating good passage performance for both sexes under a wide range of environmental conditions.

Downstream passage

Downstream migrating kelts passed the dam both via the bypass and via spill-gates before the remedial measures, and via the bypass and the nature-like fishway after the remedial measures.

Downstream passage performance was high in both years. Before the remedial measures (a high discharge - high spill year) 80 % of the kelts successfully passed the dam after an average delay of 220 minutes, whereas 96% of the kelts passed the dam after the new measures after an average, delay of just 34 minutes.

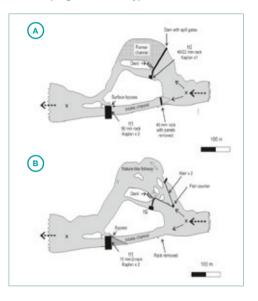
Interestingly, for downstream migrating kelts, discharge positively affected passage rate before, but not after the fishway modifications. The installation of the low-sloping intake rack contributed to making overall passage performance less dependent on spill. Indeed, after installation of the intake rack, all fish visiting the intake channel were successfully guided to the bypass.

LESSONS LEARNED

Implications of the new fish passage facilities include a 50 % increase in spawners arriving at the spawning grounds, on average one month earlier than before the modifications, and high downstream passage efficiencies and rates for kelts. Furthermore, the design and characteristics of the two fish passage solutions hold promise for high performance not only for

THE HERTING FISH PASSAGE FACILITIES

A) Before modifications fish passage was provided by a Denil fishway and a trash gate. B) After modifications fish passage was improved by the construction of a large nature-like fishway and a low-sloping rack and a bypass.



adult salmonids, but also for a range of species and life stages. Downstream migrating eels and smolts also show high passage efficiencies, and the recruitment of juvenile eels to upstream sites have substantially increased since construction of the nature-like fishway. Of the 25 migratory fish species native to the River Ätran, 15 have been registered passing through the nature-like fishway, while 19 have been documented to use the bypass.

Lastly, the large nature-like fishway reduced hydropower production by approximately 35%, and will most likely only be considered as a solution for upstream passage at sites where fish are valued higher than hydropower. The low-sloping intake rack on the other hand, had a limited impact on production and should hence be a feasible solution for most hydropower plants of similar size. In 2017 a dam removal workshop in Brazil hosted by CEMIG, one of the largest hydroelectric power generators and distributors in Brazil, demonstrated a highly progressive attitude by Brazilian industry. This was to open up a dialogue for the potential to selectively remove some dams while better optimizing the location of new dams to best protect the rich species diversity in Brazil. One of the dams discussed was Pandeiros Dam in Minas Gerais state. An inactive hydropower dam located in a national park that has been the subject of research by the Federal University of Lavras, Brazil, for potential removal for multiple years (Souza, 2017).

Africa

The predominant literature in Africa regarding dam removal is associated with legislation on

DAM REMOVALS IN SOUTH AFRICA

Robin Petersen, Navashni Govender & Stephen Midzi (SANParks, South Africa)

Kruger National Park is the flagship conservation area in South Africa. It contains 6 major rivers that traverse the park (600 km of river length) and a network of seasonal and ephemeral streams (30,000 km). These extensive drainage systems act as foci and hotspots for a huge biodiversity of aquatic species, including 53 fish species. The main anthropogenic influences that have modified these systems are impoundments. In 1931 the first concrete dam was constructed in the park, and since then a total of 53 concrete and earthen dams and weirs have been constructed along various water courses. The Park's policy of adaptive management, recognises that these act as barriers to natural migration patterns, especially for breeding fish, and impact stream flow and natural aquatic system processes. Thus, a new water resource policy has been adopted to remove a selected number of redundant dams and structures to achieve free-flowing rivers in the park.

The first dam removal was undertaken in 2001 at Black Heron, in collaboration with the South African Defence Force (SANDF) who volunteered to assist with the removal of 21 dams. To ensure the river or stream is returned to its most natural state, the Expanded Public Works Programme (EPWP), a poverty relief program, has been employed to rehabilitate sites to remove and reuse rubble. To date at least 25 dams (earthen or concrete weirs) have been either breeched or removed.

The Ngotso weir before and after removal, South Africa

This non-perennial river provides important habitats within the high rainfall season, providing spawning habitats and nursery habitats for juveniles. This dam was removed during the low rainfall season. © Stephen Midzi.





dam decommissioning as a result of either safety issues (Development Bank of Southern Africa, 2004) or following mining closures, where tailings dams need to be decommissioned. There have been very few dam removals to restore ecological integrity, although in Kruger National Park, South Africa, there have been 25 dam removals in ephemeral rivers to restore connectivity (Robin Petersen, 2017, pers. comms.).

7.2 INCENTIVES AND DRIVERS FOR DAM REMOVAL

The removal of dams is full of controversy and debate (The Aspen Institute, 2002). Although dams can provide essential services, they also have severe negative environmental, social, economic and safety concerns as detailed in chapter 4 (World Commission on Dams, 2000; Miao, *et al.*, 2015; Winemiller, *et al.*, 2016; Petts, 1984). The main incentives for dam removals are discussed below. Dam removal is quickly becoming a realistic, cost-effective and viable approach to river restoration (King, *et al.*, 2017).

7.2.1 Ecological restoration

Free-flowing rivers are probably the most imperilled ecosystems in developed regions of the world. Not only are free-flowing rivers rare, but there are many threatened species that are on the IUCN Red Data list, largely as a result of instream barrier impacts (Gangloff, 2013). Apart from the overall conservation benefits of restoring rare and important habitats and species, there are numerous other ecological advantages of dam removal. These are closely associated with restoration of ecosystem functions (flow, sediment transport, longitudinal and lateral connectivity), which is lost with dam construction and operations (Petts, 1984).

Restoring first-order impacts from dams such as water quality, sediment loads and flow regimes are the first and most obvious ecological benefits. Once nutrients, carbon and sediments are no longer impacted by dams, water quality parameters such as dissolved oxygen, temperature, pH and ammonia and sediment transport dynamics and sediment deposition, can quickly return to natural levels (US EPA, 2016). In the Kennebec River in Maine, the removal of the Edwards Dam resulted in significant improvement in overall water quality parameters and the US EPA were able to reclassify the water to a higher designated use (US EPA, 2016).

Removing a dam can also improve the natural flows that help re-expose riffles and continually recreate habitat diversity. This general improvement in habitat availability, hydrology and connectivity, in turn results in improved aquatic and terrestrial community structure and a healthy river continuum (see Chapter 2). Improved habitats and connectivity will recreate the water supply and access to spawning habitats for fluvial specialists, which can subsequently provide a food source for other freshwater, marine, and also terrestrial and avian species. Ultimately dam removal, when done carefully, can result in a restored self-sustaining, ecologically viable system that is not dependent on long term maintenance and the ample associated costs.

When dams are removed, numerous spatial and temporal changes occur (Bednarek, 2001; Duda, et al., 2008; Gregory, et al., 2002; Foley, et al., 2017). This can include changes to sediment dynamics, food web biota interactions, instream and riparian plant communities. nutrients, temperature and flow regimes. Hart, et al. (2002) shows a simple representation of the spatial and temporal changes that occur after a dam. This includes how the biotic, hydrological, morphological and primary producers change upstream of inundation zones, upstream of dam wall and downstream of the dam wall. These ecological functions also shift temporally ranging over a few days to decades. In practice for instance, after a dam is removed there is first an increase of sediment export from above the dam structure. After some years, the sediment returns to its natural sediment regimes and channel form. The magnitude, rate, duration and spatial extent all depend on various characteristics of the dam,

ΓΥΔΜΡ

The Elwha River dam removal, ecosystem response to large-scale barrier removal

Authors:

Pess G.R.¹, J. Anderson², J.A. Bountry³, S.B. Brenkman⁴, J.J. Duda⁵, M.L. McHenry⁶, J.R. McMillan⁷, R.J. Peters⁸, A.C. Ritchie⁹, A. Shaffer¹⁰ & C.M. Tonra¹¹ Organisations: ¹United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center - Seattle, WA, 2Washington Department of Fish and Wildlife -Olympia, WA, ³United States Department of Interior, Bureau of Reclamation - Denver, CO. ⁴United States Department of Interior, National Park Service, Olympic National Park - Port Angeles, WA, ⁵United States Department of the Interior, United States Geological Survey, Western Fisheries Research Center - Seattle, WA, ⁶Lower Elwha Klallam Tribe - Port Angeles, WA, ⁷Trout Unlimited - Port Angeles, WA, 8United States Department of Interior, United States Fish and Wildlife Service - Lacey, WA, 9United States Department of the Interior, United States Geological Survey Santa Cruz, CA, ¹⁰Coastal Watershed Institute - Port Angeles, WA & ¹¹The Ohio State University - Columbus, OH United States of America

Country:



INTRODUCTION

Removing two dams on the Elwha River was the largest dam removal project in the world. The 21 million m³ of sediment stored behind the dams, the most ever exposed by a dam removal project, required an adaptive management program to help guide the magnitude and rate of reservoir sediment erosion. If the rate was too fast, incomplete erosion of the remaining sediment could leave behind unstable floodplain terraces risking uncontrolled sediment releases after dam removal. If too slow, elevated suspended sediment loads would jeopardize downstream aquatic biota for many years. How reservoir sediment is ultimately redistributed drives both short-term and long-term ecosystem responses to dam removal.

WHAT DID YOU DO?

A staged deconstruction strategy was used to mitigate the effects of sediment erosion caused by removal of the dams. (Warrick et al., 2015).

TWO DAMS ON THE ELWHA RIVER BEFORE AND AFTER REMOVAL

A) Glines Canyon Dam (before removal), B) Glines Canyon (after dam removal), C) Elwha Dam (before removal), D) Elwha Canyon (after dam removal).



By concurrently removing both dams with alternating ~ 5.0 m drawdowns and 14-day hold periods (Warrick et al., 2015), sediment redistribution and erosion was monitored and allowed to keep pace with dam removal. Additional 6-8 week hold periods were used to protect migrating anadromous fishes. Whereas the Elwha dam was removed over one year, the Glines Canyon Dam was lowered according to planned increments in the first year, followed by a one year hold to mitigate water treatment, and finalized in the third year. Additional demolition in the downstream canyon below former Glines Canyon Dam was required through October 2016 to clear boulders impeding fish passage.

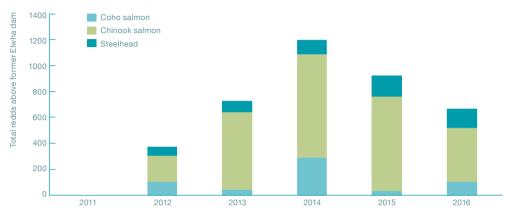
HOW DID IT WORK OUT?

The Elwha River dam removal resulted in rapid biophysical changes due to longitudinal river reconnection. Within three years, the downstream transport of tens of millions of tonnes of reservoir sediment re-established and expanded the estuarine (Foley *et al.*, 2017) and nearshore habitats. Sediment deposition in main stem and floodplain river channels caused significant bed aggradation, although that signal began to reverse after two years. This temporarily reduced benthic invertebrate density by over 90% downstream of the former dams. Decreasing benthic prey sources were offset by a higher proportion of terrestrial food sources in juvenile salmonid diet. In the first year, anadromous fish success-

>>EXAMPLE

FIGURE 1

The number of spawning nests observed upstream of the former Elwha Dam before (2011), during (2012 to 2014) and after (2015-2016) dam removal.



fully began recolonizing upstream areas from which they had been absent for 100 years (Liermann *et al.*, 2017. Differences in the condition and type of upstream habitats caused divergence in fish life history trajectories (Liermann *et al.*, 2017, Quinn *et al.*, 2017). The increase in marine marine-derived nutrients following anadromous fish recolonization (Tonra *et al.* 2015) is likely to alter the migration patterns and fecundity of an aquatic songbird riparian bird species (Tonra *et al.* 2016).

SALMONID SPECIES

Observations of several salmonid species, including chinook salmon and pink salmon © John McMillan.

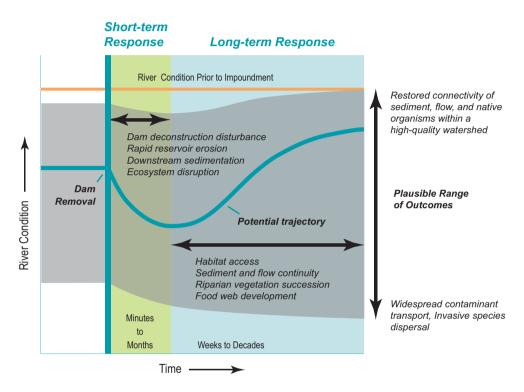
LESSONS LEARNED

Positive results and important lessons accompanied the Elwha River dam removal project. Steep mountain stream channels are efficient at processing large amounts of stored sediment. Sediment redistribution results in rapid changes in habitat and species composition. Migratory species exploit restored ecosystem connectivity by rapidly utilizing newly-opened habitats. Quantifying the biological and physical responses to dam removal requires multiple scientific lenses focused over multiple years before, during, and after dam removal. Thus understanding ecosystem response to dam removal requires cross-disciplinary collaborations for a holistic understanding of ecosystem benefits.



Figure 7.2

Conceptual temporal and spatial responses to dam removal as represented by Foley, et al., 2017. Before the dam removal the physical and ecological river conditions are likely altered from changes in flow, sediment and connectivity. After the dam is removed there is a short-term disturbance, which recovers to a new steady state. This steady state is dependent on the watershed conditions. The Potential trajectory represents one of many possible outcomes that can occur within the grey shaded area.



river, watershed and method of dam removal (Hart, *et al.*, 2002). The fluctuations can be easily shown in the conceptual river response (Foley, *et al.*, 2017). Figure 7.2 shows how the conditions of a river vary depending on many different processes. The potential trajectory, depicted within the *grey shaded area*, is just one of many possible outcomes. This depends on the original impacts of dam development and operation, the magnitude of those impacts, removal strategies and regional environmental conditions. With shifting climatic baselines, the river that comes back could be notably different from the river that was impounded decades or centuries earlier.

Adverse ecological impacts

It is important to note adverse ecological impacts associated with the removal of dams. These are some of the long- and short-term impacts as observed, and reviewed by Doyle, *et al.* (2003), Hart, *et al.* (2002), Bednarek (2001) and US EPA (2016). In summary, these issues include (Downs & Gregory, 2004):

- Water Quality
 - Increased turbidity after dam removal;
 - Deterioration in water quality from released contaminants accumulated in stored sediments;

DAM REMOVAL AND CLIMATE CHANGE

Kerry Brink (World Fish Migration Foundation, The Netherlands)

Apart from the direct advantages of dam removal, there are also benefits for increasing climate change resilience. Researchers have shown that rivers impacted by dams will require greater management action to mitigate the impacts of climate change, than basins with free-flowing rivers (Palmer, *et al.*, 2008). A map derived by the authors showed how river discharge can potentially change under different climate change scenarios for both dam-impacted and un-impacted rivers. Flow reductions, altered seasonality and increased temperatures, potentially resulting from climate change, can ultimately exacerbate the dam-related ecological, physical and socioeconomic impacts. Taking a look at declining flows shows how this can result in fragmentation of biotic populations, altered seasonality and reduced natural refugia, which ultimately influence natural ecological processes. This is in addition to direct flow modifications, changes in nutrient cycles and stratification.

More recently, research has started to show a more direct correlation between greenhouse gas emissions (significant drivers of climate change) and dams (Deemer, *et al.*, 2016). This has resulted in new questioning of the perception that hydropower dams are emission free or carbon neutral (Fearnside, 2016). In a study by de Faria, *et al.* (2015), models on 18 planned and constructed hydropower dams in the Brazilian Amazon suggested that greenhouse emissions could be greater than from electricity generation based on fossil fuels. Thus, suggesting that such dams would have a significantly negative impact on climate change gases, particularly in the tropics.

There are also positive and neutral implications of dams in areas potentially vulnerable to the effects of climate change. Beatty, *et al.* (2017) argued that dams can act as refugia for increasingly imperilled freshwater fishes and can also prevent the spread of invasive alien species in rivers.

Severn River 2007 floodings

This is a photo of the River Severn, a highly regulated river, where mass flooding occurred in 2007 after heavy rainfall in July 2007. Tewkesbury in Gloucestershire was particularly badly hit where the River Severn and its tributary the River Avon meet. The White Bear pub in Tewkesbury was cut off and surrounded by flood waters. UK, 2007. © Global Warming Images/ WWF.



Hydrology

- · Impacted elevation of the groundwater table;
- · Potential loss in wetland area;
- Regrading of floodplain is sometimes required within the former impoundment to ensure adequate floodplain functionality;
- Ecology
 - Abrasion or burying of aquatic plants, animals and habitat;
 - Changes to channel morphology resulting in channel incision or aggradation;
 - Colonization of invasive or exotic plants or animals;
 - Catchment alterations;
- Sediment issues
 - Changes in dynamics of sediment transport to downstream reaches (can be both negative or positive).

7.2.2 Fish passage

Disruption to fish migration is probably the most common ecological reason for removing dams. In Sweden, a review of dam removals showed that out of 17 case studies, the creation of fish passage opportunity was one of the main reasons for removal in 12 of the case studies (Lejon, *et al.*, 2009).

Numerous cases have indeed shown the positive responses of dam removal on migration routes around the world (Dam Removal Europe, 2016; Restoring Europe's Rivers, 2016). Exemplary projects resulted in the improvement of native trout communities in Spain after the removal of the Inturia Dam (Almandoz, 2016). Improved passage to more than 2,600 km of habitat for salmon, shad, alewife, blueback herring and eels in the Penobscot River in Maine resulted in fish returns of a few thousand in 2012 increasing to nearly two million in 2016, USA (Royte, 2016).

Another example of positive benefits comes from the Loire River in France where, in 1998, a dam was removed to provide access to salmon spawning grounds. In 1999, a year after the dam was removed, there were already signs of new salmon recruitment with more than five new salmon spawning sites in areas upstream of the former dam (Lejon, *et al.*, 2009; Bomassi, 2010; European Rivers Network, 1998).

Another major dam removal project was the Elwha River Restoration Project in Washington state in the USA, implemented to rehabilitate Pacific salmon runs (Duda, *et al.*, 2008; Pess, *et al.*, 2008; Bellmore, *et al.*, 2016). Following the removal of dams in the Elwha it was reported

SUMMARY OF KEY ECOLOGICAL RESPONSES TO DAM REMOVAL AS STATED BY FOLEY, *ET AL*. (2017)

- 1 Physical responses are typically fast, with the rate of sediment erosion largely dependent on sediment characteristics at the time of removal and the damremoval process;
- 2 Ecological responses to dam removal will differ among the affected upstream, downstream, and reservoir reaches;
- 3 Dam removal tends to quickly reestablish aquatic connectivity, restoring the movement of material and organisms between upstream and downstream river reaches;
- 4 Geographic context, river history, and current and historic land use significantly influence river restoration trajectories and recovery potential as they control broader physical and ecological processes and conditions; and
- 5 Quantitative modelling capabilities are improving, providing better insights to post-dam physical and broad-scale ecological effects, and can give managers information needed to understand and predict long-term effects of dam removal on riverine ecosystems. This is often crucial for communities around dams who are eager for information on what change will look like with a restored river.

in 2015 that there were excess of 4,000 king salmon and 1,200 steelhead trout according to the lower Elwha Kialiam Tribe. As restoration proceeds, scientists are hoping to double these figures and hope to see more Chum, Pink and Coho salmon.

7.2.3 Safety

One of the most common incentives for river managers to remove dams is to resolve safety issues. In many dam removal cases, including many reported in the USA, safety and economic arguments are often the final factors that help determine whether a dam will be removed (Wildman, 2013). Dam safety has long since been an international concern. In 1928 the International Congress on Large Dams (ICOLD) was formed with its first international Congress held in 1933 in Stockholm, Sweden, with 21 member countries in attendance (ICOLD, 2017).

In the USA approximately 64% of all dams are privately owned, 20% are owned by local governments, and only 7% are owned by state agencies. The remaining 9% are owned by federal government, public utilities, and undetermined interests (ADSO, 2017). Dam safety is primarily the responsibility of the individual states. All of the states, other than Alabama, have state dam safety programs. The federal government has no direct responsibility or authority concerning the safety of non-federal dams, thus the definition of a regulated dam and the specific regulations governing dams can vary significantly between states. However after a series of dam failures in the 1970's and 1980's that resulted in significant loss of lives, extensive infrastructure damage, negative financial implications, and environmental damage, the federal government decided to increase their involvement in dam safety and provide guidance on model dam safety programs.

The National Dam Safety Program, led by the Federal Emergency Management Agency (FEMA) to protect Americans from dam failure, was then established in 1996 (FEMA, 2013). As a result of all this, there are a significant number of dam regulations requiring regular inspections, maintenance, and preparation of Emergency Action Plans for dams, and in some cases the lowering or removal of unsafe dams. The cost to keep dams maintained in accordance with the regulations is often a key driver for many dam removals in the USA. Dam removal can often be a less expensive option, especially if the impoundment sediments are free of contaminants and there are not potential impacts to surrounding infrastructure. Costs for repairs of old dams in Wisconsin for example, was estimated at about three to five times more than that of dam removal (Sarakinos & Johnson, 2003).

In Europe and other regions of the world, similar dam safety regulations exist, although the standards and procedures in dam safety legislation vary considerably by country (Kreft-Burman, *et al.*, 2005). Each country having its own definition of a regulated dam, with a wide variety of regulation that typically require regular inspections, maintenance and the preparation of Emergency Action Plans, similar to the USA requirements.

Dam ownership varies widely (ICOLD European Club, 2014). In the Netherlands and Slovinia the majority of all dams are owned by public agencies. In Spain the dams are typically publically owned, but grant concessions to private companies to utilize the dam. In Italy approximately 60% of the dams are privately owned by hydroelectric companies and the rest by public entities, while the majority of regulated dams are owned by hydroelectric companies in Switzerland and Sweden. While in Norway and Romania the dams are typically owned by hydropower and water supply companies, as well as water authorities.

Countries with publically owned dams typically regulate the dams out of a central federal agency, and countries such as Germany and Italy regulate their dams out of numerous regional water authorities. ICOLD's European Dam Safety Club has reported on dam safety regulations in 14 out of the 15 European countries they investigated (ICOLD European Club, 2014). Only Ireland was found to have no legislation governing the regulation of dams during their latest 2014 legislative update. According to their report in Ireland dam safety practiced are solely the responsibility of the dam owners.

While the specific regulations differ between the European countries, all of the dam safety regulations stipulate that the dam owner/ operators are fully responsible for consequences in case of a dam failure and typically require dams to therefore be maintained to ensure public safety (ICOLD European Club, 2012). However the literature regarding the role that the European dam safety regulations and maintenance costs play in the removal of dams in Europe is scarce.

7.2.4 Economics

The economic benefits of both maintaining old dams and building future dams are increasingly questioned. As indicated above, maintenance and repairs of old dams is often more expensive than simply removing them. In many cases where dams have been removed in the US, the decision was based on the prohibitive costs of repair and the lack of economic benefit (Born, *et al.*, 1998).

Although not always recognised by communities, there are opportunities for economic growth once dams have been removed (Graber, 2003; Amercian Rivers, 1999). Recreational fishing can have a high economic value which can significantly increase once connectivity has been restored and fish populations have become reestablished. There are also recreational activities such as kayaking and canoeing that can attract tourists to a re-opened environment.

Further benefits include community revitalization, increased aesthetic appeal, local business booms and, not least, a cost-effective way to improve catchment scale river habitats that can rejuvenate fisheries and allow the return of migratory fish.

In the Conestoga River in USA, 17 dams were removed at a cost of \$1 million (Graber, 2003). This resulted in the return of large numbers of American shad, which had been absent for more than 80 years. This ultimately resulted in rejuvenated fisheries that were expected to generate approximately \$2-3 million revenue for local economies.

In a Swedish review, a dam removal at Storsjö-Kapell was shown to quadruple fish stocks, increasing the value of a fishing day for local fishermen (Lejon & Nilsson, 2009).

There can also be economic losses with dam removal such as the dam owner's decreased economic benefits resulting from lost hydropower operation, and issues such as declines in lakeside property values and recreational value associated with the impoundment once a dam has been removed (American Rivers & Trout Unlimited, 2002). The challenge is for decision makers to find the balance between cost-benefit ratios when comparing dam removal and dam repair alternatives.

This is also the case when assessing future dam developments. According to Winemiller, *et al.* (2016) planners in developing countries generally fail to assess the true benefits and costs of large hydropower developments. Using the case of the Three Gorges Dam in China, the authors showed that billions are to be spent to moderate ecological impacts caused by dams and, in many instances, these costs are frequently excluded or underestimated during the economic projections of the projects.

In the context of river restoration alone, dam removal has also been considered as a more viable restoration solution when compared to other possible measures. In France, dam removal began to gain traction from around 1996, during which time there was increasing evidence that the installation of fishways was not only inefficient in compensating for the reduction in fish populations, but were also very costly (Epple, 2016). REFORM Restoration WIKI (2016) have started consolidating evidence from restoration projects around Europe including information

DAM REMOVAL AROUND







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- A The impoundment of the Glines Canyon Dam after removal. The river is starting to cut out its own course in the accumulated sediments, Washington state, USA. © Herman Wanningen.
- B Spoonville dam during removal. Taking the dam out was one step in a multi-part, long-range effort to restore historic fish migrations in the Farmington River, USA. © Laura Wildman.
- C Carpenters Dam during removal, the last dam on the Quinnipiac River, Connecticut, USA. © Laura Wildman.
- D The Sélune is a coastal river that flows into the bay of Mont Saint-Michel. In 2017 the removal of 2 main dams was ordered by the French government. © Roberto Appele/ERN.
- E Retuerta dam site after removal, this dam was 14 m high and 55 m wide. The Duero Basin Authority decided to demolish the dam in 2013. © Confederación Hidrográfica del Duero.
- F Arase dam before removal in 2009. The removal will be completed in 2018. The flow of the river has almost returned after 60 years. Kumagawa River, Japan. © Shoko Tsuru
- G Pandeiros Dam on the Pandeiros River (Brazil), a tributary of the São Francisco River. The reservoir suffers from excessive sedimentation and has now been decommissioned. Removal is likely to be a viable option. © Paulo Pompeu.
- H Cofio River after removal of the Robledo de Chavela dam, Spain.
 © Confederación Hidrográfica del Tajo.
- Former location of the Shisakashanghondzo dam, Kruger Park, South Africa. It took members of the South African National Defence Force (SANDF) special forces school three days and eight tonnes of explosives to blow up the dam © Richard Sowry/SANParks.
- J Removal of Manyweathers Weir, fish superhighways programme, New South Wales, Australia. © Matthew Gordos.

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THE WORLD

5)



Social and economic value of free-flowing rivers

A) Improved recreational opportunities after dam removal can improve economic opportunities in a region. Here, people enjoy the tranquillity of a free-flowing section of a river during World Fish Migration Day 2016, Suur Taevaskoda, Estonia. © Jurgen Karvak. B) Angler in search of Atlantic salmon in the free-flowing Vatnsa River, Iceland. Iceland is considered to have a low freshwater biodiversity, due to geographic isolation, a northern location and the relatively young age of its ecosystems, but it is an important home for Atlantic salmon. © Wilco de Bruijne. C) Kayakers on the Zrmanja River, Balkan Rivers Tour campaign. © Jan Pirnat. In the Balkans (Central Europe) over 2500 new hydropower dams are planned in pristine and free-flowing rivers (www.balkanrivers.net).







on fishway costs. As expected, the costs for restoration projects varied substantially as shown in a review by REFORM in their inventory of river restoration measures: effects, costs and benefits (Ayres, *et al.*, 2014). In Switzerland the construction of the Albbruck Dogern fishway cost an estimated \in 4 million, whereas Garcia de Leaniz (2008) estimated costs of removing weirs in Spain to vary from just under \in 2,000 for small dams to over \in 90,000 for larger projects.

7.2.5 Societal concerns

Even with incentives relating to safety, economics and ecology, public perception of dam removal can ultimately alter the final decision on dam removal (Sarakinos & Johnson, 2003; Magilligan, *et al.*, 2016). In many community's dam removal is currently a contentious issue, associated with economics (as described above), current use, current and future benefits, and sentimental value. Many of the concerns are related to recreation, property value, and aesthetics. The latter is one of the biggest and most consistent concerns in the US, where Sarakinos & Jonson (2003) argue there is greater preference for still-water views rather than flowing water views. These perceptions also differ considerably throughout the world. A channelized canal can be seen as a significant improvement a river in some parts of the world.

In Europe, some dams have a high historical and societal value, which can influence the decisionmaking process (Garcia de Leaniz, 2008). A number of dams in southern Europe that date back to Roman times are still in use, including the Proserpina Dam, Cornalvo Dam and the Almansa Dam in Spain. In the UK, there is a national society devoted to the protection of watermills and their associated weirs. In Australia, concerns such as loss of irrigation water has been a major source of conflict in the Murray-Darling Basin (Beatty, *et al.*, 2013).

It is possible to alleviate these fears and misconceptions of stakeholders with images from completed projects, computer-generated visual simulations of restored rivers, and by providing a plan for what the former impoundment and river will eventually become.

7.2.5 Policy & legislation

Policy and legislation are perhaps the most critical drivers in the process of in initiating dam removal projects around the world. USA and Europe have

Photo rendering tool for dam removal projects

Photo renderings of sites can be presented at public stakeholder meetings during the dam removal design and development process to help alleviate fears and misconceptions. This often offers the local community a vision for the future, instead of just describing it or justifying an approach with scientific data, and can help alleviate fears and build consensus. Here is an example of Swanton Dam in Vermont, USA and an image of what the river would look like after the dam removal. © Laura Wildman.





by far the greatest amount of information available relating to dam removal policy and legislation and as such will be the focus of this discussion.

In Europe, since the initiation of the EU Water Framework Directive (WFD), the removal of barriers tends to be institutionalized, where member states are required to have regulations in place that seek to achieve good qualitative status of water bodies (Germaine & Lespez, 2017). This means that local and national member states are obligated to consider practical actions to promote, restore and guide restoration efforts. Although the regulations vary significantly between European countries, the primary driver for dam removal seems to be derived from the high-level policies related to improving ecological status.

In the USA a series of environmental regulations including the Clean Water Act, the Endangered Species Act (ESA), and multiple acts governing the balancing of environmental and hydropower interests, has led to numerous pro-active dam removals for the purpose of restoration. In addition, there are multiple dam safety regulations and laws that are designed to guide the decommissioning process of dams that are deemed to be unsafe.

Europe

Dam removal in Europe is largely supported by national policy and legislation related to the protection and enhancement of biodiversity. In Sweden their Environmental Objectives include 16 ecosystem goals that should be reached by 2020. This includes an objective that promotes thriving wetlands and biodiversity and another sub-goal to restore 25% of valuable and potentially valuable rivers and streams (Lejon, *et al.*, 2009). The Swedish Environmental Code and Water Framework Directive (WFD) are the key legislation driving this environmental restoration.

In the UK, the Environment Agency (England) and Natural Resources Wales are empowered under the Salmon and Freshwater Fisheries Act (1975), the Marine and Coastal Access Act 2009, and the Eel Regulations (England and Wales) 2009 to improve connectivity for fish (Elbourne, *et al.*, 2013).

In other European countries that are a part of the EU there are regional policies and regulations, which all ultimately require and facilitate the state to meet their obligations under EU legislation. This includes WFD, Habitat directive and EU Eel Regulations (Altmayer, 2017). Also see Chapter 6.

In compliance with the WFD, different countries have developed a range of programmes and projects. For Spain, the Ministry of Environment passed the "Estrategia Nacional de Restauración de Ríos", which has promoted dam removal plans around Spain (Bruafo, 2008). While in Scotland has implemented new legislation (Fish Passage Regulations) to facilitate improvement of migratory connectivity where this is constraining achievement of Good Ecological Status (GES).

In France, a law was initiated in 2006 which has resulted in the removing of many stream barriers (Germaine & Lespez, 2017). There is furthermore a very well-structured organisation of people involved in the management of river systems and restoration. This includes the:

- French Agency of Biodiversity who enforce national government laws and WFD applications;
- Water Agencies who manage the major water basins and develop major basin management plans;
- Within the water agencies there are three smaller minor water basin departments (EPTB, AFB and DDT) that are involved in minor water basin management, site inspections, and ensure activities in the basin are legal and ensure that policies are well implemented. DDT department collects and updates inventories of river obstacles;
- Municipalities along with the Association of Municipalities focus on local river management and operational plans.

These European organisations often work together. in a sometimes, complex interdependence of activities that has ultimately resulted in the removal of thousands of obstacles, including a total of of 2,435 naturally and artificially removed obstacles and 5,728 partially removed obstacles (Sandre, 2017).

The number of river and stream obstacles removed has been further driven by economic support available from environmental grants, which can pay up to 80% of dam removal (Dam Removal Europe, 2017).

Specific laws relating to dam removal as a strategy to restore water resources are however, sparse. In England, dam removal is considered a relatively new technique, and as such there is limited information and less legislation supporting the removal of dams (Environment Agency, 2010). In many cases there is legislation pertaining to dam decommissioning, but these exists for public safety (ICOLD European Club, 2014). In England and Wales for instance the Reservoir Act (1975) primarily exists to protect public safety issues and has rarely, if ever, led to dam removal for restoration purposes.

USA

Federal, state and local laws and regulations all play a role in the decision-making process for dam removal (Grabowski, *et al.*, 2017). Apart from the federal laws that underline most decisions, each state also has their own individual laws, sometimes very different, as well as policies and programs that affect dam removal.

Historically dam safety and hydropower regulation has been the most common legal proceeding, however in recent years environmental restoration has played a larger role, which has been governed by federal laws such as the ESA and fish passage laws (Bowman, 2002).

To summarize, environmentally focused legislation that can influence dam removals in the USA include:

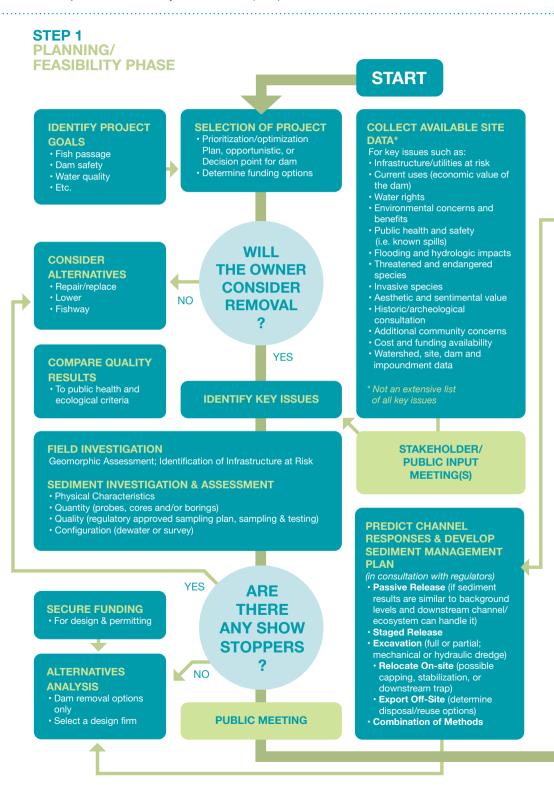
- Fish passage laws, which can motivate environmental agencies to prioritize and pursue removals;
- Wetlands protection laws;
- Endangered Species Act which can influence relicensing of dams and fish passage requirements and standards;
- · Pollution standards from the Clean Water Act;
- The National Environmental Policy Act (NEPA);
- · State derivatives can also influence removals.

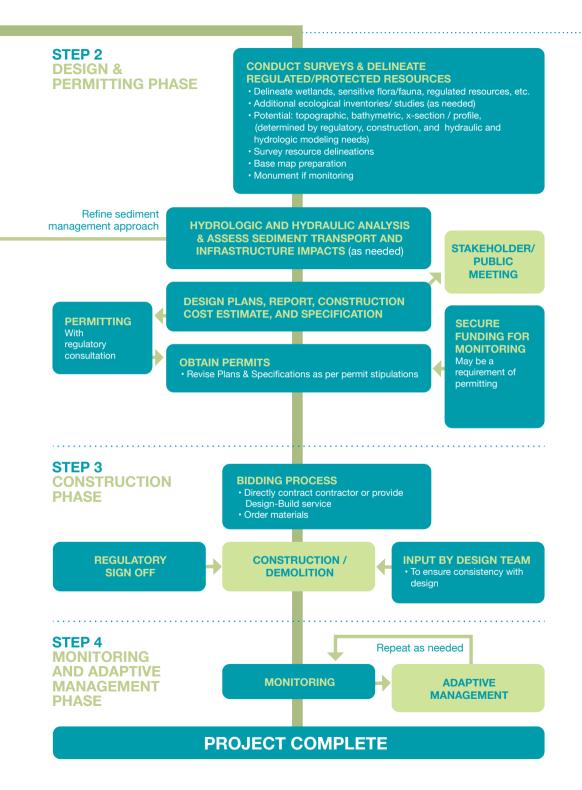
If a dam is considered unsafe, the state often has the authority, under the dam safety legislation, to permit, inspect and compel owners to conduct inspections and take action to repair or possibly even remove the dam if it consistently fails to meet safety standards. Removal however is less common and only implemented in a few states.

Once the decision has been made to remove a dam, there are numerous federal and state permitting requirements that must also be considered (Lindloff & Wildman, 2006). In the USA, most of the existing laws and regulations that would lead to dam removal were not developed with actual dam removal in mind. Making a dam removal decision is thus challenging within the current framework. As explained in The Aspen Institute policy report (2002), dam removal projects designed to provide restoration benefits are viewed in the same way as development projects that are not intended for restoration. The process for removal typically includes permits from multiple agencies, which can be a lengthy and costly process. There is a multitude of different federal, state and municipal permits required (ICF Consulting, 2005), however some states have now greatly simplified the process by creating general permits for relatively simple dam removal efforts, including Pennsylvania and Connecticut.

7.3 BASIC STEPS TO DAM REMOVAL

There are four basic steps that should be taken when considering dam removal as a means of river restoration including a) the feasibility and planning phase, b) a design and permitting phase, Figure 7.3 Flow chart summarising the four basic steps that should be considered within the dam removal process as derived by Laura Wildman (2017).





EXAMPLE

River Usk SAC: removal of a small weir on Afon Menasgin

Author: Organisation: Country: Stephen Marsh-Smith The Wye and Usk Foundation Wales



It's generally believed that the best option is to remove an obstacle to fish migration as it has many advantages over providing a fish pass or easement: potentially a lot less cost and ongoing maintenance than a fish pass, plus it is the method of choice for downstream migration of juveniles: the dead space upstream of a weir and the 'thin water' at the crest can be problematic for parr and smolts migrating downstream.

However, there are examples where removal is not possible. In England and Wales there are many historic or 'heritage' structures associated with early irrigation schemes or milling that had been in place for hundreds of years. This is an account of a weir removal project that overcame some of those problems.

There are two weirs on the Afon Menasgin, a tributary of the River Usk SAC in southeast Wales. Its steep gradient and pure water makes it ideal for spawning salmonids. The lower weir is passable in good flows to salmon and trout, but 1 km upstream was an impassable weir: its dilapidated state ruled out a fish pass as it would have required a complete rebuild but it held back enough water to continue supplying enough water to irrigate several fields and fill a lake several km

THE OLD WEIR BEFORE REMOVAL © The Wye and Usk Foundation.



A NEW WEIR HAS BEEN BUILT UPSTREAM TO ENABLE WATER EXTRACTION © The Wye and Usk Foundation.



away. On the basis of its badly broken down state, we sought and gained approval from the owners and consenting authorities for removal.

The overall plan included the securing continuity of a water supply for the lake by taking it from a

OLD WEIR BEING REMOVED © The Wye and Usk Foundation.



more distant point upstream. The construction of the weir was typical of that era: dressed stone fitted into a robust wooden framework and blockstone crest. The fact that the frame was still there along with a series of 'generational' concrete repairs might have suggested a larger machine would be needed but the 10 tonner used eventually completed the task.

With the weir gone, there was a period of settling down. However, the accumulated stone and silt departed in just one small flood and over the next year, the vegetation grew back covering the scars of removal. Following the next spawning season, we saw evidence of salmon redds (spawning sites) upstream.

The compromise was in the small weir that was built upstream for the water take off. The pictures show how it worked and that it was a relatively small barrier to trout and salmon, who would almost certainly not get this far upstream with additional flows. The new weir upstream to enable water to be taken off with central notch to aid fish passage. c) the construction or deconstruction phase and
 d) a monitoring and adaptive management phase.
 Within each of these steps there is a multitude of
 criteria that need to be evaluated and considered.
 These steps may differ significantly between
 regions, which may add or limit process steps.

We suggest a conceptual model as a starting

guideline toward the dam removal processes (Figure 7.3). It must be noted that this is a generalized scheme that can vary significantly depending on the project and region. The model is predominantly based on the American approach (American Rivers & Trout Unlimited, 2002; The Aspen Institute, 2002) and provided by Laura Wildman (2017, pers. comms.).

DAM REMOVAL TAKES A LEAP FORWARD IN EUROPE

Pao Fernández Garrido (World Fish Migration Foundation, Spain), Herman Wanningen (World Fish Migration Foundation, The Netherlands), Bart Geenen (WWF The Netherlands), & Jeroen van Herk (Dam Removal Europe, The Netherlands)

Free-flowing rivers are the arteries of Europe's ecosystems. A large part of European biodiversity is connected to rivers, wetlands and deltas. But currently, there are hardly any free-flowing rivers left in Europe as we have been fragmenting rivers for centuries by the construction of dams and weirs.

Dam Removal Europe (DRE) is a Europe-wide dedicated coalition of organizations with the objective to bring back life to our rivers by removing old, obsolete dams and to 'free' our European rivers again (www.damremoval.eu). Dam Removal Europe was started by 6 organizations: the World Fish Migration Foundation, World Wildlife Fund, Karlstad University, European Rivers Network, the Rivers Trust and Rewilding Europe. Currently it is a strong and growing network of authorities, NGO's, companies and knowledge institutes from many different European countries working on dam removal.

The objective of DRE is to gain recognition of removal of old. obsolete dams as the most eco-efficient and cost-effective measure for river restoration. It is clear that after the removal of dams, river ecosystems recuperate quickly and strongly. It can be a strong measure for authorities to meet the requirements of the Water Framework Directive, DRE facilitates the development and exchange of knowledge on Dam Removal between partners in different countries. It does so to inspire others, so that jointly we can protect and restore our great European rivers.

Boñar Weir

Celebration of the start of Dam Removal Europe at the Boñar Weir removal (Porma River, Spain). © Herman Wanningen.



CHAPTER 8 TECHNICAL SOLUTIONS FOR HAZARDS AND

OBSTACLES

Fishway Geestacht in the River Elbe. © Herman Wanningen.

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 learn from failings and make improvements to develop the most effective and efficient fish passes possible. Freeflowing rivers are however still preferred and fish passes are used as an alternative when barrier removal is not possible.

Increasingly we are learning the value of international exchange and dissemination of fish passage information.

Many studies have been undertaken on the subject of fish passage facilities, but knowledge gaps still exist. A wide range of disciplines including fish behaviour, socioeconomics and complex modelling of passage prioritization remain part of our current challenge (Silva, et al., 2017). It is no longer enough to design passage for single species solutions, as attention is increasingly multispecies and focused more toward holistic stream ecosystem approaches. Fishway design in river restoration projects demands this transition towards more functional river systems.



8.1 FISH MIGRATION FACILITIES: THE CURRENT PICTURE

The free migration of fish up and downstream and into and out of floodplains is essential for completing their lifecycles and maintaining healthy populations at optimal levels. Most species of fish migrate during some part of their life cycle, not just the better known long-range migrants such as salmon, dourado and eel. The challenge of providing multiple fish species passage up artificial barriers is well known, however the lesser known issues around downstream migration are equally critical, yet relatively unrecognised (Williams *et al.*, 2011).

8.1.1 Upstream facilities for fish migration

Fish pass facilities to provide upstream migration, principally for salmon, river herring and sea trout, have existed since the early 19th centuary in Europe and the USA. The first fishway in Brazil was the Igarapava fishway on the Pardo River, build in 1911 (Closs et al., 2016). In some countries, fish pass solutions date back to the 18th century or even earlier. Some of the earliest passes were ineffective, largely because of poor construction, incomplete understanding of the swimming capabilities of fish, of hydraulics at different flow levels, and insufficient regular and long-term maintenance of the structures. This often resulted in a change of strategy from maintaining natural fish runs, to financial compensation for loss of stocks, or to fish stocking.

Most work has been on 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 sturgeons (*Acipenser* spp., *Beluga* spp.). This was clearly due to the high economic value of these species to commercial and recreational fisheries, and sometimes because these species were protected by law. Protective legislation in the UK for salmon, for example, is known from the 15th century.

Modern day dam licensing requirements often mandate adequate passage of fish to meet numeric, timing and efficiency goals. Together with whole river system restoration work, there is now a modern era of intensive fish pass research based on field testing, improved monitoring efforts and small-scale fish pass models (Denil, 1909; Pryce-Tannat, 1937; Larinier et al., 1992; Clay, 1995; Pavlov, 1989; Gebler, 1998). This is quickly leading 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 passes (Larinier, 2001), orifice, vertical slot and nature-like fishways have also become commonly used. Fish passage 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 there is still a significant ecological impact of the primary structure on which these fish passes are built.

Semi-natural solutions such as bypass channels, nature-like channels around obstacles, and inriver rock ramps are increasingly used instead of technical fishways. These structures require more space, as they must generally be installed at low gradients, however their appearance can be attractive as they mimick local nature and therefore they are proving to be increasingly popular. These also tend to be lower maintenance, if built well, they can function at a diversity of flows and have few if any moving parts needed to manipulate stream flow through the bypass verses through a dam or weir.

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 altogether. Wherever this is feasible, when considered against hydraulic and flood risk changes, as well as economic factors, this option should be vigorously pursued.

The biggest problem in constructing upstream fish passage facilities is generally financial

PECIES EXAN

Fishways for a big, iconic fish: Australia's Murray cod

Authors:

Country:

Ivor Stuart & John Koehn Organisation: Arthur Rylah Institute for Environmental Research Australia



INTRODUCTION

Australia's largest freshwater fish is the iconic Murray cod (Maccullochella peelii), which often grows to 1.4 m long, reaching weights of 45 kg and living to 48-years old. Once common throughout the 1M² km Murray-Darling Basin, their populations have severely declined and they are now a federally threatened species (Lintermans, 2007). Part of the reason for this decline is the dams and weirs interrupting their migrations and turning their preferred flowing river habitats with 'snags' (fallen trees) into slow flowing weir pools.

MURRAY COD

Australia's iconic Murray cod, typically growing to 1.4 m long and 45 kg, this fish migrated through a fishway on the Murray River. © Lee Baumgartner.



FIGURE 1

Australia's Murray-Darling Basin (shaded), covering over 1M² km of Murray cod habitat across 5 jurisdictions, with the Murray River (dark line).



SOLUTIONS

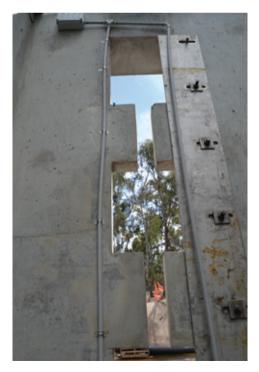
In the past 15 years, the Murray-Darling Basin Authority, which manages natural resources within the MDB has invested AUD\$77M to improve connectivity along 2225 km of the Murray River (Barrett and Mallen-Cooper, 2006). Fifteen new fishways now provide opportunities for upstream migration of the whole native fish community, including Murray cod (Baumgartner *et al.*, 2014) and have been a catalyst for ongoing construction of many other fishways on major tributaries in Victoria, New South Wales, South Australia and Queensland.

Large-bodied fish (i.e. >1 m long) present a range of practical challenges for fishway designers, such as those for giant Mekong catfish in south-east Asia and sturgeon in the United States (Thiem *et al.*, 2011). Risks to large fish are especially evident at hydropower stations where a high proportion of flow passes through turbines (Stuart *et al.*, 2010). In our Murray cod case-study, the additional challenge was securing passage for the whole fish community (20+ species) including smallbodied (<50 mm long) species and Murray cod in the same fishway. To meet this challenge, fish ecologists and fishway designers first determined the range of river flows on which Murray cod move. From radio-tracking studies, adult Murray cod are known to move from their home snag for spawning and, along with juveniles, are frequently collected in fishways (Koehn *et al.*, 2009; Leigh and Zampatti, 2013; Koehn and Nicol, 2016). Murray cod are one of few MDB fish that also migrate during the very infrequent high flows (e.g. <1% of time, historically); so effective fishways were required to operate from low flows right up to drown-out of the weir.

In the first few years of the Murray fishway program, low gradient vertical-slot fishways were constructed and successfully passed both small and large fish from 40 mm to 1 m

'KEYHOLE' SLOT

A vertical-slot fishway with an innovative 'keyhole' slot which can pass small and large fish.



A PROTOTYPE TRAPEZOIDAL FISHWAY WHICH MAY BE USEFUL FOR PASSING LARGE FISH © M. Mallen-Cooper.



long. The large fish required large, deep pools

with wide slots (0.3 m), whilst turbulence and water velocity were minimised for the passage of small fish. Monitoring revealed that these fishways were highly successful for some species but did not efficiently pass the abundant small (i.e. <50 mm long) species or the uncommon but ecologically important largest Murray cod (>1 m long; Stuart et al., 2008). To augment these findings, longterm data sets were also available from fishways built in the 1990s, at Torrumbarrv and Yarrawonga weirs, where 1140 and 1852 Murray cod successfully passed in 26 and 17 years of monitoring, respectively.

LOOK TO THE FUTURE

New directions for Murray cod passage now include: (i) 'keyhole' slots that have a flared wide opening (e.g. 0.35 m) and also slots with a narrower opening (e.g. 0.2 m) to minimise turbulence but still allow large fish passage, (ii) construction at a site of two fishways with separate ecological/hydraulic functions, one for small and one for large fish, (iii) testing of entirely new fishways, such as the trapezoidal design, and (iv) delivery of environmental flows to support fishway function. For Australia's Murray cod, research learning over the past 20 years and innovative fishways play a key role in ongoing population recovery.

Fish migration facilities

A) The St Martin fish pass in the Ardeche River, France. © Marq Redeker. B) Hadley Falls Station fishlift on the Connecticut River, USA. © Marq Redeker. C) Bypass channel Harkortsee in the Ruhr River, Germany. © Ruhrverband.



constraint. Dam removal is almost always less expensive than technical fish passage solutions, but often are hampered by social issues. Effective solutions in highly populated areas or at highhead hydroelectric dams presents significant technical challenges. Often the constraints are whether to allocate the large amount of private or public funds needed to do this effectively and with the long-term commitment to maintain, monitor results and adjust management or the structure as needed to meet fish passage goals.

The large number of obstructions, occasionally more than a thousand in some rivers, means that restoring the free migration of fish is prohibitively costly. 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 100 fish passes have been built in the last five years; this is relatively slow progress against the 25,000 known artificial stream barriers. Unfortunately around 5,000 of those barriers will be needed to address. Water Framework Directive (WFD) commitments. This costly list of solutions is common around the world. To improve the rate and quality of river restoration 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 has been renewed ambition over the past 10 vears for fish migration improvement through these organisations, working either independently or in collaboration with the Environment Agency (the Government regulatory authority in England) and Natural Resources Wales.

8.1.2 Downstream facilities for fish migration

Problems for downstream migration are relevant to juvenile as well as adult phases of some species. Significant problems for safe and timely downstream migration of all fish in Europe have only recently been widely acknowledged. This will need to be addressed more carefully around the world wherever free-flowing rivers have been or will be fragmented. The issues with securing downstream passage are different from upstream, in that many obstructions are apparently easily passable in the downstream direction. There are several key exceptions to this. Firstly, some fish are naturally reluctant to pass over the obstruction, or they may be unable to readily find a safe route downstream. More frequently barriers have water extraction facilities into which the migrants might be entrained. Both are significant problems for fish and more work is needed to understand how they may be effectively resolved. Downstream migrants generally take advantage of principal currents to save energy, but this leaves small or weak-swimming fish in particular, little time to react to water intakes, even if they are physically capable and elect to do so, in order to avoid areas of potential danger.

The increasing demand for hydropower globally,

and especially the current great interest in lowhead hydropower, is due to rapidly emerging demands for renewable energy. This is a major problem for fisheries around the world and the people that survive on them. Provision for effectively screening and bypassing facilities at hydropower developments is a legal requirement in some countries, such as the UK, but in many cases this is sufficiently expensive to erode the economic case for development. In other countries, there is currently no such legal protection (see Chapter 6).

Effective fish protection facilities for downstream passage are often much more difficult and complex to achieve than the facilities for upstream fish migration. The problems for downstream migration when extracting water for mills. navigation channels, hydropower, for commercial use or for agriculture or drinking water supply are widely recognised in most European countries. Experience resolving these problems is available in many countries e.g. Denmark, Germany, France, Sweden and the UK. In these countries and in North America, problems for downstream migration have been examined but not sufficiently resolved for diadromous species, in particular salmonids and eel (e.g. Larinier, 2001). There is also little information and experience available for other species, because until recently, there was little concern for them.

Today, a large number of technical 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 given the amounts river-borne debris, the increase in extreme high flows, and in some regions ice. Behavioural solutions are attractive, but despite many examples, there is little convincing evidence of their success in influencing behaviours of a range of fish. A fully satisfactory solution, outside of dam removal has not yet been devised, and

Table 8.1 Selection of technical guidelines and manuals

Guideline or manual	Country	Reference
Culvert Fishway Planning and Design Guidelines	Australia	Kapitzke, 2010
Environment Agency Fish Pass Manual	United Kingdom	Armstrong, et al., 2010
The ICE protocol for ecological continuity, Assessing	France	Baudion, et al., 2014
the passage of obstacles by fish. Concepts, design and		
application		
Performance, Operation and Maintenance Guidelines for	Australia	O'Connor, et al., 2015
Fishways and Fish Passage Works		
Federal Interagency Naturelike Fishway Passage Design	USA	Turek, et al., 2016
Guidelines for Atlantic Coast Diadromous Fishes		
Fish Passage Engineering Design Criteria. USFWS,	USA	USFWS, 2017
Northeast Region R5, Hadley, Massachusetts		

••••••

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 and mortality occur. Behavioural exclusion systems have varying degrees of success and are often custom designed for a specific location and require precise operation of the device.

In the USA studies to adapt turbine design for safe fish migration have been increasing (e.g. Cada, et al., 1997) so that passage through hydropower turbines may be or become less damaging over time. The emerging popularity of Archimedes screw turbines in Europe appears to offer a solution that seems to be relatively benign to fish.

Still sufficiently effective and reliable facilities for downstream fish passage and protection of fish at intakes are not yet widely available, and may not even be fully achievable. Further research, innovation, trials, monitoring, and adaptation is needed.

8.2 FISH PASS DESIGN & 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 and guidelines for restoration of upstream and downstream fish passage and also on the experience of the authors. Unfortunately not all of these are available in English and are therefore not available for worldwide use. Table 8.1 shows a selection of some of the more recent (national) design guidelines and manuals that are available in the English language.

Specific design criteria:

- · See different technical manuals;
- · Future monitoring requirements;
- · Health and safety.

Each of these steps is discussed further in this chapter, including the identification of need, the starting points and general principles. It should be noted that some solutions for hazards and obstacles apply to both upstream and downstream fish passage. 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 separate structures for upstream and downstream migrants may be required. Therefore, each step described here deals with upstream and downstream migration separately.

FXAMP

Re-opening the Rhine River for fish

Authors:

Country:

& Marc de Roov **Organisations: Ministry of Infrastructure** & Water management The Netherlands

Pieter Beeldman, Koen Workel



INTRODUCTION

The Rhine River flows through several European countries, including Switzerland, France, Belgium and Germany, before it reaches the Dutch delta where it flows into the North Sea. In the past many fish species, such as Atlantic salmon, sea trout, European eel and Atlantic sturgeon migrated between the sea and the rivers upstream.

But due to water quality deterioration, hydromorphological changes in the river, construction of weirs and dams and overfishing, fish stocks decreased dramatically. The Atlantic sturgeon disappeared completely from these river systems.

The countries that share the Rhine river basin started the International Commission for the Protection of the Rhine in the 1980s to try to turn the tide. Many plans were drawn to improve ecological quality of the river from its source to the sea, including a Salmon Action Plan. Member states installed fishways at weirs, dams and sluices along the main stem and implemented measures to improve the habitat of several migratory fish species. Also a salmon re-introduction plan was started. For more information see: www.iksr.org/en

Hundreds of millions of euros have now been invested over the past 30 years by member states to improve the ecological quality of the Rhine.

BUILDING BARRIERS AND PROTECTING THE NETHERLANDS FROM FLOODING

After the severe flooding of the South-West of the Netherlands in 1953, the Dutch government decided to install a Dutch Delta Plan. Dykes were strengthened along the Dutch coastline and dams, storm surge barriers and sluices were built. The Dutch estuaries of the Rhine and Meuse rivers were closed as a consequence of this. In 1970 the Haringvliet, located at the mouth of the river, was closed by the 1 km long Haringvliet sluices. The sluices were installed to act both as a storm surge barrier and to discharge surplus water. The annual average freshwater discharge is around 30 billion m³, which is discharged at low tide. For the rest of the tidal cycle the discharge sluices are closed. Due to the high velocities at low tide and the fact that the sluices are closed during high tides, migratory fish cannot migrate from the sea into the river system. The entrance of the Rhine river basin had been closed to fish. As a consequence of the Haringvliet sluices, the intertidal Haringvliet became a stagnant freshwater system, which was also used as a fresh water supply.

Different species of fish spend parts of their lifecycles in these brackish intertidal zones where they are able to acclimatise from salt to freshwater and to live for parts of their life cycles. But overall the measures that provided security for man had a huge negative impact on migratory fish stock.

FIGURE 1

Map of the river basin of the Rivers Rhine and Meuse and the position of weirs and sluices (red and purple figures) 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. All three weirs in the Lek/Nederrijn have fish passes.



WHAT DID YOU DO?

In 2000 the Dutch government decided that migration possibilities at the Haringvliet sluices should be restored. This was the so-called 'Kier' decision.

The decision is that the sluices will opened 'partly' at high tide so that 16 species of migratory fish will no longer have to cope with high velocities and so can enter the river system again during a certain window of opportunity. Salt water will be allowed to flow into the Haringvliet again where a brackish water system will develop with limited tidal amplitude.

The solution was the result of advice from an

>>EXAMPLE

HARINGVLIET SLUICES

In 2018 these Haringvliet sluices will be opened for migratory fish. © Carel Midde.



international advisory group. As part of this, compensation measures have been taken since 2012 to safeguard the drinking water supply and freshwater supply from the Haringvliet that is required for agricultural functions. Freshwater intakes were moved more than 12 km upstream from the Haringvliet sluices, after consultation by the Regional Water Authority Hollandse Delta and the Drinking water company Evides.

In the autumn of 2018 the Haringvliet sluices will be opened for the first time, restoring the crucial fish migration route after 40 years. A fish migration highway towards the upstream rivers will at last be open again.

LEARNING BY DOING

Monitoring and evaluation will be an important aspect of the next steps in the process. The 'Kier' decision says that the freshwater intakes is not allowed to be affected by salt intrusion. There is limited experience with the dispersion of salt water in the Haringvliet Therefore a salt water monitoring framework has been installed and the data will be used to grow experience in salt water behaviour and to manage salt water intrusion within the limits set by the water managers. The data will also be used to optimise management of the Haringvliet sluices.

During the next few years, monitoring of fish migration at the Haringvliet sluices and the fish stocks upstream will be undertaken to find the optimal migration window for migratory fish.

8.3 STEP 1: DEFINITION

The definition phase comprises a study of the existing situation and constraining factors for migration, local features and conditions, target species, seasonality of migration and a conceptual plan 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, ecologically, financially, and sometimes socially.

8.3.1 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 barriers to fish migration might be unique to certain areas or, more often, are characteristic for geomorphic river types; rivers and streams in high gradient systems, lowlands, estuaries and coastal zones. 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 fish passage concept might be identified. The concept should be informed by the long-term plan or vision for the river basin, which would be partly ecological, but also a reflection of local societal needs. The plan will be influenced by the characteristics and topography 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, life stage/size, and in what hydrological conditions do they need to migrate?
- What is 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?

The vision for the river basin and specifically for the river reach and its place in the larger stream network should be central to the strategy to improve fish passage opportunity.

Target species

Target fish 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 identify through recreation or sampling efforts. 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. Ideally the

Nature-like fishways

A) A full width rock-ramp fishway with low flow channel in the Karuah River, Australia. © Martin Mallen Cooper. B) Natural-like fishway bypassing the dam of the Beyenburger Stausee, Wupper River, Germany. © Wilco de Bruijne.





THE THREE BASIC STEPS

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 downstream.

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 an ecological status defined by ecological targets.

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, location of dams, stream connections, quantitative estimates of habitats and other potential obstacles or opportunities for fish passage protection or restoration.

STEP 3

For both upstream and downstream migration

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

Priorities of measures

fish passage designed for the target species will enable most or all of the resident and migratory fish to pass, and if necessary exclude unwanted fish, such as exotic invasive species.

Every fish species has its own characteristic swimming capacity and typical behaviour. The swimming capacity depends on the fish's morphology, condition and length, and the water temperature during their migration. Behaviour of fish is variable between species, and will also vary on a seasonal and daily basis in response to a wide range of factors. Behavioural issues of relevance include migratory habits of the fish as individuals or in schools in the river channel during migration, their residence time at barriers, the rate of onset of maturation and responses to hydraulic parameters and light (among other responses).

Choice of solution

Passage can almost always be secured by the 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 evaluating the potential risks, but the option should always be fully explored in the context of the river's health, long-term economics, and societal risk of barrier failure as well as societal dependence or preference for the structure.

When removal is not possible, reducing the barrier height or construction of semi-natural solutions such as nature-like bypasses or rock ramps or the use of pre-barrages should be considered next.

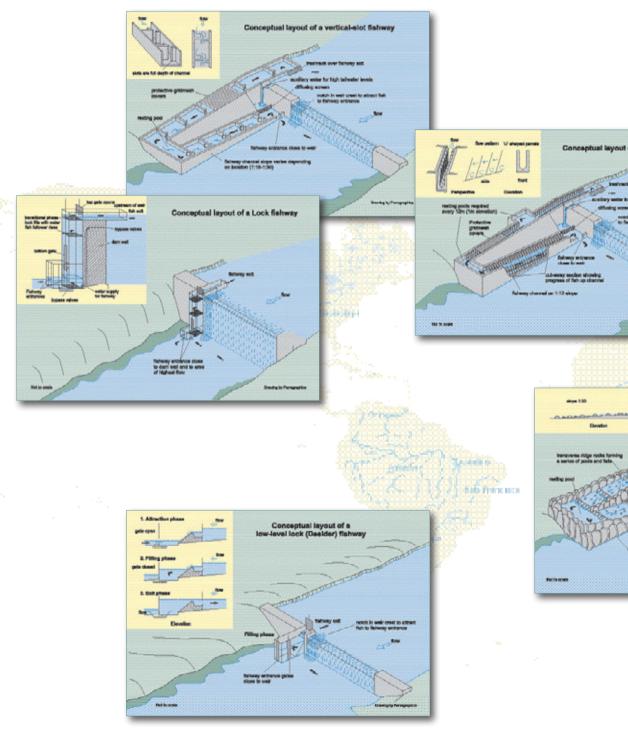
The installation of simple passage devices, such as flow deflectors that help larger fish such as salmon to migrate upstream should also be considered, however many such structures do not provide passage opportunity for smaller species.

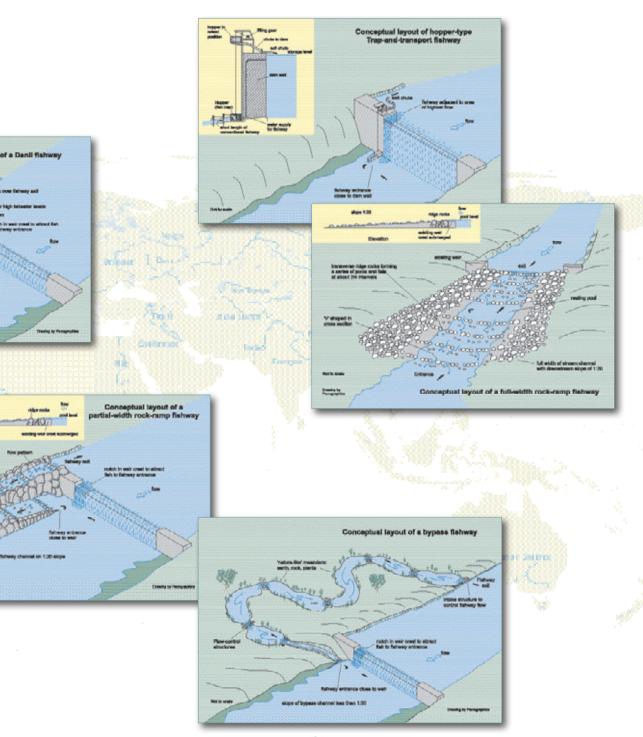
Technical solutions for fish passage are variously referred to as fishways, fish passes, fish passages. bypasses, fish lifts and fish ladders. The new EU-standard on fish pass evaluations uses the term fish passage solutions (FPS), which includes both up- and downstream passage and all kinds of fish passes. 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. This makes designing a single passage structure to function adequately for the whole fish assemblage, difficult or impossible.

In the past, most of the focus for fish passage design has been on securing passage for principal species such as salmon, eel and shad. Fortunately, this is changing in more and more countries where improving the overall ecological status of the river 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 migratory fauna (remembering there are anadromous shrimp, mammals such as freshwater dolphins, manatees, etc.) wherever this is technically feasible. Where it is not, an explicit management statement should be made so that river basin goals may be moderated and resources allocated to river networks that have more significant passage needs.

Taking all of these factors into account, together with other locally specific constraints and conditions (e.g. the type of water body, target species, and the management of the structure etc.) and the financial scope for action, the optimal passage solution for a migration barrier can be identified.

FISHWAYS THORNCROFT AND HARRIS, 2000 SCHEMATIC OVERVIEW OF VARIOUS FISHWAYS





EXAMPLE

Fish Migration River, Breaking down a large barrier without jeopardizing safety and water quality

Authors:	Erik Bruins Slot ¹ , Katja Phillippart ² ,
	Roef Mulder ³ & Herman Wanningen ⁴
Organisations:	¹ Province Fryslan, ² Waddenacademie,
	³ De Nieuwe Afsluitdijk & ⁴ World Fish
	Migration Foundation
Country:	The Netherlands



INTRODUCTION

Large parts of The Netherlands are located below sea level and inhabitants of these areas are protected by an extensive and sophisticated system of dikes, pumps and sluices. One of the greatest technical achievements was the construction of the 32 km long dam ("Afsluitdijk") in 1932, dividing the former estuary of the river IJssel (part of the Rhine delta system) into a marine intertidal area (western Wadden Sea) in the north and a freshwater storage basin (Lake IJssel) in the south. Although large parts of this area are now protected against flooding, the construction of the dam can also be regarded

FIGURE 1 Location of the FMR in The Netherlands.



as one of the largest ecological disasters in the recent history of this area. Former brackish habitats and species completely disappeared and fish migration from the sea to the rivers became seriously hampered.

The ongoing decline in fish stocks on both sides of the dam called for action to restore connectivity. Removing the dam or even periodic opening up the dam without any additional measures was not an option, because of the risk of flooding during storm surges and of the strict regulations with respect to the salinity of the freshwater storage basin. In addition, migratory fish were expected to require tidal dynamics to be able to travel (in particular small specimens such as flounder larvae) and brackish conditions to be able to adapt from marine to freshwater conditions. Fish ecologists and engineers jointly came up with an innovative design that meets all these requirements, facilitating migration for the wide range of species present: the so-called Fish Migration River (FMR).

WHAT DID YOU DO?

The first idea for a FMR was launched in 2011 by a consortium of non-governmental organizations (NGOs). A feasibility study suggested a technical solution of opening up

FIGURE 2 Artist impression of the FMR in the Afsluitdijk.



.....

the dam without jeopardizing water quality by creating a long meandering tidal channel between the sea and the freshwater basin. Fish migration experts from all over the world were consulted to provide further advice and detail to inform design and engineering considerations, including the possible impacts of currents, light and noise on fish migration success. Amongst other occasions, the plans were presented and discussed during the international Fish Passage Conferences in 2015 (Groningen, NL), 2016 (Amherst, US) and 2017 (Portland, US).

In addition to the requirements with respect to fish migration and water quality, added values such as the aesthetics of the design and attractiveness for tourism were considered during the planning phase. Because a FMR of this size has never been built before, it called for an adaptive design and a monitoring program, so that its construction and management could be optimized during operation. The experts further considered it to be crucial to gather detailed on-site information on migratory behavior in response to local environmental conditions, not only to optimize the design and management of the FMR itself, but also to gain generic knowledge on functioning of this innovative type of fish passage which could then be applied worldwide.

HOW DID IT WORK OUT?

The final design of the FMR covers a total area of 50 hectares, encompassing a 25 m wide and 4 km long tidal channel together with a scientific testing facility. Flood safety and restriction of seawater entering the freshwater basin is guaranteed by means of sluices at the freshwater end of the channel, which close automatically at high tide. Approximately 200,000 m³ of seawater will enter the basin during flood tides, whilst 500,000 m³ of water flow out to sea during the ebb, resulting in a net seaward outflow of freshwater of 300,000 m³ of per tide.

In the central brackish part of the FMR, incoming tidal waters follow a flood channel, whilst the outgoing flow is funnelled through an ebb channel. The sand-based design not only suits the environment, but also provides maximum flexibility for adaptive reconstruction during the operation. The scientific testing facility (just south of the brackish tidal part of the structure) allows for changing local conditions to study impacts on fish migration without disrupting the functioning of the FMR itself.

The funding of the FMR project, with a total budget of 55 million Euro, has been secured by means of regional, national and European grants

>>EXAMPLE

such as TENT-T, LIFE, Nationale Postcode Loterij and Waddenfonds. The budget is not only allocated for construction of the FMR, but also includes resources for management, monitoring and research. FMR research on fish migration will be linked with other local (fish passage though freshwater discharge sluices in the Afsluitdijk), regional (Wadden Sea "swimway") and national studies, including the effects of opening up the dam in the Haringvliet, the southern outfall of the river Rhine. Furthermore, the FMR will welcome fish migration scientists and students from all over the world to perform their own experiments in this unique large-scale fish passage in an estuarine tidal environment.

LESSONS LEARNED

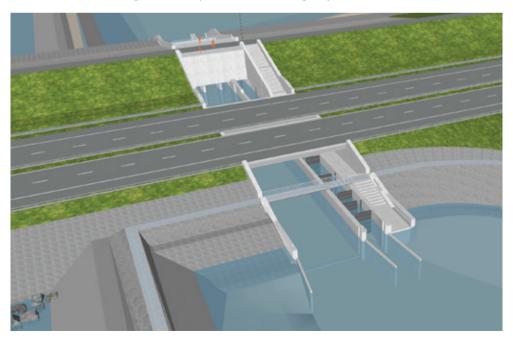
What once started as a first sketch in 2011, and was then designed in 2017, will be contracted in 2018, built in 2019 and opened in 2023. Clearly, such rapid development from plan to realization

can only be accomplished if the needs for improving fish migration are broadly recognized and promoted (e.g. by NGOs), if collectives of ecologists and engineers are able to come up with feasible designs, and if government officials and funders are open to support innovative solutions.

The adaptive design phase, including continuous interactions with stakeholders and an international expert team, enabled fast progress in identifying and solving potential bottle-necks in the construction. Although the success of this unique development cannot be considered certain at this stage, and specifically whether it will facilitate fish migration as much as intended, the adjoining monitoring program and testing facility provide the best possible evidence to improve functioning and facilitate restoration of river connectivity without compromising water quality and safety.

FIGURE 3

Detail of the FMR crossing the Afsluitdijk and A7 National Highway.



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 the barrier height);
- 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).

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 as already explained in chapter 7 of this book.

Ad 2

Semi-natural solutions, e.g. bypass channels and controlled flooding

If it is not possible to fully restore the full natural regime, then a semi-natural solution should be pursued by creating an artificial, though nature-like, channel around, through or over the dam or weir. These can partially resolve fish migration issues while potentially contributing extra habitat or holding areas for a range of fish species as documented in the case study above. The barrier remains fully or partly in place and the risks of bank stability, potential social issues with the impoundment (firefighting water, boat ramps), historical nature or look of the structure are therefore moderated or potentially eliminated.

Natural	Semi natural	Technical	Adapted management
 Removing dams and weirs Removing weirs in combination with restoration of natural habitat Removing dykes and restoration of floodplains Restoration of estuaries 	 Nature-like bypass Pool-riffle fishway Riprap; rock ramp fishways Step-pool; cascade fishways Restoration of partial tidal exchange Restoration of temporal flooding areas/wetlands 	 Pool fishway with overfall weirs Pool fishway with vertical slots Pool fishway with submerged orifices Tube and siphon fishway Fish lock Fish lock Fish lift Baffle ("Denil" or "Larinier") fishway Fishways for eel and elvers Screw jack (Archimedes screw) fishway Fish save pumps Fish friendly culverts 	 Estuarine constructions (e.g. discharge sluices) Adjusted sills (weirs with underflow) Shipping locks Daily or weekly "open times" where, for example, sluices are raised or opened

Table 8.2 Overview of solutions to restore upstream migrations

HABITAT COMPENSATION IN NATURE-LIKE FISHWAYS Stina Gustafsson (Karlstad University, Sweden)

The construction of nature-like fishways has become an increasingly common measure to restore longitudinal connectivity in streams and rivers affected by hydroelectric development. These fishways also have the potential to provide additional habitat as compensation measures when running waters have been degraded or lost. The habitat potential is often overlooked, and therefore the aim of my work was to examine the potential of nature-like fishways for habitat compensation, with a special focus on the effect of added habitat heterogeneity.

Field research in the Eldbäcken biocanal © Herman Wanningen & Olle Calles.







The work examined the effects of habitat diversity on the macroinvertebrate family composition and functional organisation in a nature-like, biocanal-type fishway (Gustafsson, 2017).

The biocanal in Eldbäcken, situated in the Västerdalälven river system in Sweden, contains four habitat types: riffle, pool, braided channel and floodplain. The effects of habitat diversity and large woody debris on brown trout habitat choice was investigated in the biocanal. Prior to introduction of the threatened freshwater pearl mussel into the biocanal, the suitability of different brown trout strains as hosts for the mussel was examined.

The results show that habitat heterogeneity in the biocanal contributed to an increased macroinvertebrate family diversity. The functional organisation of the macroinvertebrate community suggests that it was a heterotrophic system and more functionally similar to the main river than to the small streams that it was created to resemble. Brown trout habitat choice studies showed that high densities of large woody debris increased the probability of fish remaining at the site of release. Testing of different brown trout strains as hosts for the freshwater pearl mussel revealed that both wild and hatchery-reared brown trout strains were suitable.

In summary, the results indicate that it is possible to create a fish passage with added value through its high habitat function, and that nature-like fishways can be designed to deliver multiple species restoration goals.

Ad 3

Technical solutions, e.g. fishways and fishlifts

If it is not possible to achieve free passage through a natural or semi-natural solution, then the next option to consider is a technical solution, or formal fish pass. Formal fish passes can contribute to securing longitudinal and lateral migration, but by their nature they do not add habitat nor restore natural hydromorphology within the impounded reach of the river. Nevertheless, they can effectively resolve some fish passage issues where more natural alternatives cannot be used. Technical fish passes are probably the most frequently used solution for restoration of fish passage worldwide.

Ad 4

Adjusted management, e.g. opening sluices and locks

Some barriers can be managed specifically to enable fish passage. There are many ways management can be adjusted to increase fish passage effectiveness. 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 a management change. Adjusting operations in this way can be an almost zero-cost solution and may even be superior to a technical fish pass as much larger attraction flows may be available. For example, when the migration of Alabama shad was blocked by a navigation lock on Florida's Apalachicola River (USA), The Nature Conservancy's Steve Herrington pumped water through a PVC pipe into the upstream end of the lock to create the sound of running water. This attracted shad into the lock creating a successful migration upstream so populations increased from 10,000 to over 75,000 and are expected to grow to around a half million fish annually.

8.3.2 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 extraction and hydropower generation. Although downstream migrating fish can often safely pass

SPECIES EXAMPLE

The upstream struggles of Inanga (Galaxias maculatus)

Authors: Organisation:

Country:

Katharina Doehring¹ & Paul Franklin² ¹Cawthron Institute & ²National Institute of Water and Atmospheric Research New Zealand

INTRODUCTION

Inanga, *Galaxias maculatus*, is a migratory fish native to New Zealand and several countries across the Southern Hemisphere. They are the most common of the five 'whitebait' species, a culinary delicacy in New Zealand. Inanga are mostly amphidromous; larvae migrate downstream to the ocean where early development occurs, they then return to freshwater habitats as juveniles, and mature in freshwater. Adults are small (ca. 110 mm), brown-green with a silvery belly, preferring lowland freshwater habitats (e.g., coastal creeks and streams). An unusual feature of their life-cycle is that eggs develop 'out of the water' on grassy banks at the margin between marine and fresh waters.

A LARGE ADULT INANGA (GALAXIAS MACULATUS) © Paul Franklin.



Inanga face many struggles. Human-induced pressures on freshwater habitats, such as urbanisation and agricultural intensification, have degraded New Zealand's waterways. Obstacles to fish passage are a major issue in small, lowland streams where they require unimpeded movement to complete spawning and feeding.

POSSIBLE SOLUTIONS

Inanga undertake their main upstream migration as small-bodied juveniles (35-60 mm). They are relatively weak swimmers and lack the climbing ability of the other 'whitebait' species. Drops as small as 5 cm are known to impede their movements (Baker, 2003). Structures, such as culverts and weirs, limit movements in streams thereby restricting the range of accessible habitats.

Applied research on remediating existing fish migration barriers has focused on cost-effective solutions to overcome outlet drops and high water velocities in culverts. Fish ramps and baffling have proven effective solutions (e.g. Doehring *et al.*, 2012; Franklin & Bartels, 2012; Baker, 2014). Novel use of mussel spat ropes as a baffling material also improves passage (David *et al.*, 2014).

Fortunately, we are now seeing fish passage considered in local and national legislation (e.g., National Environmental Standard for Plantation Forestry) and cross-disciplinary initiatives (i.e., New Zealand Fish Passage Advisory Group (www.doc.govt.nz/fishpassage) to improve management).

WHAT ARE THE KEY DRIVERS?

Inanga are a taonga (treasured) species in Māori culture, highly valued as a traditional food source and indicator of the mauri (life supporting capacity) of freshwaters. While they still support important recreational and cultural fisheries, they are ranked as 'At Risk-Declining' (i.e., the lowest threatened species classification in New Zealand) due to increasing concerns about the status of populations.

Recentnationallegislativechangesandincreasing social awareness about the decline of our freshwater systems are key drivers of enhanced protection. Fundamental to this is ensuring that the habitats that support iconic species, such as Inanga, are protected and restored.

LOOK TO THE FUTURE

Promoting the importance of connectivity has gained traction with national and regional authorities, resulting in better fish passage management. Cross-disciplinary communication between the many industries involved in planning water infrastructure (e.g. road authorities, consultancies, ecologists, engineers) is also crucial to providing effective fish passage. Clear national guidance and monitoring tools will lead to adoption of best-practice approaches for the installation of culverts, weirs and dams. Finally, raising awareness of the many struggles of Inanga and engaging with community-led stream care groups will result in habitat improvements and the installation of cost-effective and simple fish passes to fix migration barriers.

MUSSEL SPAT ROPES

Mussel spat ropes enhance upstream passage of juvenile fish, including inanga, through culverts. © Bruno David.



over low weirs, a water intake structure, can draw fish into intakes and thereby cause injury and serious mortality. If the rates of extraction are high then fish mortality can reach serious levels. For the many redundant low-head weirs where there are no longer any water withdrawals, passage may be straightforward although with some species delay may result from reluctance of fish to pass over the weir.

Uncontrolled fish passage over high-head dams, either as overspill or water discharged through siphons or sluicing, is inevitably highly dangerous for fish whether juveniles or adults. 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, rocks, or other hard structures below.

Passage past dams and weirs can expose fish to predators that often accumulate on either side of the dams to take advantage of delayed or exhausted fish, and downstream of such structures to take advantage of dead, wounded or disoriented fish (also see Chapter 3). In lowland countries pumping stations present 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 are strongly dependent on local situations. 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 extracted. Other features include channel morphology in the vicinity of the water intake, as this can determine the route fish may take as they approach the structure. and the location at which they assemble prior to passage. The depth where water is drawn-off is also important as well as the flow rates and velocity patterns at that point. Light and sound conditions underwater, the local occurrence and behaviour of floating or semi-buoyant sediment, structures, debris and trash are also key. Fish migration may occur at high flows so understanding of local flow characteristics in extreme conditions will be critical to understand. As such, comprehensive local knowledge of call relevant features in the full range of conditions is essential.

Relevant technical features of the water intake site of a fish passage include: design engineering and layout, the management protocol under the full range of flows, and any technical and licensing conditions that constrain water extraction, including the development of any minimum ecological flows. The nature of the extraction, including the type of any turbine, the hydraulic features including binternal pressures, bypass flow and residual flow in the river, and the fish species present will together influence the extent of damage and the rate of mortality fish experience.

Although every site is unique, various formulae have been developed to predict the mortality rate at Francis and Kaplan turbines in France (Larinier, *et al.*, 2002). 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 might 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, however, be very expensive.

In some situations, it is possible that the spillway can function as a bypass. Surface bypasses with

fairly strong flows that are located close to the water intake screens can also be effectivefor fish passage. Indeed, the provision of such facilities is usually a specific requirement of the licencing process that seeks to minimise environmental

Problems and solutions for downstream migration

A) Outlets of the smolt bypasses for downstream migration at the fishway at Gamsheim, Rhine River, German French border. © Wilco de Bruijne. B) Adult salmon in front of the trashrack at Edsforsen hydropower dam in the Klarälven River. These salmons were migrating downstream and were either damaged or died. Telemetry studies show that there is an urgent need for improved passage conditions. © Herman Wanningen. C) Vertical bar rack at the hydropower station at Roermond, directing smolts to a bypass in the background. © Wilco de Bruijne.







Mechanical barriers	Behavioural barriers or screening	Bypasses	Adjusted management
 Passive mesh screen Vertical/inclined bar racks Rotary disc screen Coanda screen Smolt safeTM screen Band or drum screen Passive wedge wire cylinder screen (PWWC) Small aperture wedge wire panel screens Sub gravel intakes and wells Marine Life Exclusion System (MLESTM) Barrier nets Modular inclined screen Self-cleaning belt screens Labyrinth screen 	 Louvre screen Bubble screen Electric barrier Acoustic barrier Light based systems Turbulent attraction flow Attractive flowing water sound Surface collector 	 Full-depth bypass Surface bypass Bottom bypass Bottom gallery Venturi bypass Lock Navigation lock Fish pass 	 Seasonal or daily adjustments to the amount of water abstracted (temporary closure)

Table 8.3 Overview of facilities for safe fish passage downstream

harm. The distribution of water between the extraction site and the spillway will almost always directly influence the proportion of fish that pass over the spillway. Careful design of the structure and well-planned and tested management of it in all conditions should be required to maximise escapement.

Target species

General principles, but also local knowledge will help determine which species should be protected at all water extraction points. 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 in most developed countries and are generally determined based on known physiological and life history information as well as fishery records.

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 fish losses on the population is negligible and can be absorbed, for example through density-dependent mechanisms elsewhere;
- A species is already locally extirpated with no 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

Managers should first determine whether the objectives for secure migration can be met by moderation of the existing water extraction or pumping regime, or by re-siting of the intakes and screens. If this is not possible, then other suitable facilities for protection of downstream migration should be selected or developed to eliminate entrainment risk or reduce it to acceptable levels.

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 or away from dangerous areas 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 or nightly closure of turbines) and other methods;
- 5 A combination of some or all of the above.

Ad 1

Mechanical barrier

Many different mechanical barriers have been developed for a wide range of scenarios of river size, water extraction type and fish species. Passive wedge wire cylindrical screens, down to 3 mm gap size (or sometimes even smaller, say 2 mm), are generally considered to be the best method for physical exclusion of fish on small-scale sites, with up to 100% effectiveness. Angled and inclined bar racks applied at larger sites can achieve > 80-90 %.

The selection of appropriate screen bar spacing is important for protection of the target fish species and life stage to be achieved while minimizing adverse impacts on water extraction. It is important to note that fast flows through any screen may kill fish through impingement. One way to avoid this is by managing the intake orientation (angle) and surface area to reduce approach velocities so fish can escape. Some European countries have regulations for screening. For instance the French government has adopted 20 mm as a required gap size, whereas in some German states 15 mm is being used. In the UK a bar spacing of 12 mm is often used to protect salmonid smolts. There is a growing need for a more standard set of gap sizes that will prevent fish of different species from being damaged.

Ad 2

Behavioural barriers

The use of behavioural barriers such as acoustic barriers to exclude fish from water extraction 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 a 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 (flooded with sound) at a location from which they have the swimming capacity to effectively respond to, and avoid entrainment and impingement. Behavioural barriers are very species-specific, with no currently known system for some species. A system that protects all fish species is therefore not yet available.

Ad 3

Bypass systems

The use of mechanical or behavioural barriers can minimise or possibly in some cases eliminate entrainment of fish, however an alternative migration route or bypass system (also known as a by-wash) is clearly necessary if successful migration is to occur with no undue delay. For fish that migrate near the water surface, there are published criteria for the positioning and design

Compact fishway design

A) Trapezoid fishway integrating an attraction flow, small fish passage and a gauging station in the Wyong River, Australia © Martin Mallen Cooper. B) Detail of the vertical slot fishway at Iffezheim, Rhine River, Germany © Wilco de Bruijne.





of bypasses in small to middle sized rivers. 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 bypass systems are currently under development, but yet to be proven safe. A fulldepth bypass, or bypasses with entrances both at the bottom and at the surface could be considered to be the ideal solutions.

An alternative is to catch fish and transport them around the barrier, especially when multiple hazards need to be passed. This is clearly very resource-intensive, expensive and 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 water intake system in order to prevent or minimise damage to fish. This may consist of seasonal or daily adjustments to the amount of water extracted, or to setting requirements for the residual flows that must be left in the river. In some jurisdictions, like in Maine USA, not more than 10% of any three-month average flow can be taken from the river until the river exceeds a certain flood level when more can be taken. 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 less damage (for example with blunt leading vane edges) and adjusted turbine management can all help to reduce fish strikes and mortality. Some designs of turbine, for example Archimedes screws, are far safer for fish passage than others, e.g. Kaplan turbines. Modern methods of CFD (Computerised Fluid Dynamic modelling) is increasingly used to refine turbine design to achieve a smooth and therefore comparatively fish-friendly flow line through the turbine housing.

8.4 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."

8.4.1 Upstream fish migration

To ensure a fish passage solution is attractive to fish and readily passible, appropriate guidelines for design need to be determined by biological criteria appropriate for the target fish species. 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 comprehensive technical manuals are identified in the list of references. A list of guidelines is also available on the website www.fromseatosource.com. 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 rely more heavily on the location of the entrance, the apportionment of flow (e.g. Armstrong, et al., 2010) 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, so flows will need to be sensitive to the time of year and species migrating at that time. Monitoring fish arrivals and environmental cues such as temperature of the rivers and ocean, if nearby, are often helpful to predicting this, but it can vary from one river system to another.

Passability

Attracting fish into the fish pass is the most critical element for any fish pass. Thereafter, if it has been built to provide conditions within the swimming capabilities of the fish it should be passable. There are some conditions that may still get in the way of successful movement through the fish pass, such as the presence of predators, sometimes loud sounds, abrupt changes in the angle of the passage (e.g. some fish do not like 180 degree bends in the channel) or the pass might not accommodate the numbers of fish needed to create a functioning school.

Attraction

Attraction is critical for fish passage and would

A vital factor is the flow pattern within the fish

Nature-like fishway in the Sabie River, Kruger National Park, South Africa

During normal (A) and high flow (B) conditions. © Peter Paul Schollema/Gordon O'Brien.





pass. Waterways such as nature-like fishways containing heterogeneous and therefore more natural flow patterns are generally easier for a wider range of migrating fish species to pass than many technical fish passes can provide. Naturelike fishways are constructed at lower gradients and therefore take up much more room than technical passes, which are often used when space is restricted and the total change in water level or head height needs to be surmounted 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 and tested in a variety of natural flows to guarantee effective passability for each of the target species.

Important design criteria for fishways include:

- The height and configuration of drops between pools;
- The nature of the flow between pools (plunging or streaming);
- Flow velocities;
- Turbulence (energy density);
- Water depth especially in the approach to drops or steps;
- The width of pools and slots;
- Adding natural substrate to the pools.

For many species, notably cyprinids, it is best to have a diversity of flow velocities and microhabitats 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 for people as well as the fish including viewing sites along the channel or bridges over it. In some cases these are highly visited attractions to rivers during migration season, building appreciation for fish and connecting people to rivers and natural cycles. Stones or woody structures roughen the bottom and promote the passage of fish and other fauna (invertebrates). Stones and boulders placed on the bed of technical pool passes can achieve the same effect and can often provide more path choices for fish of different sizes. Adding structure into a fishway generally requires accounting for the volume and hydraulic changes in the design phase.

8.4.2 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 extraction devices are operating.

The first step in designing fish protection at water intakes, is to set goals for the proportion of migrants of all species that need to survive passage for reasons of stock maintenance or fishery support. Then a team of biologists, hydrologists, and engineers can determine what solution provides the best protection for downstream migrants, and define the related design and management criteria. The cumulative impact of multiple barriers and water extractions must be considered where relevant. The final design should protect target species from entrainment, perhaps by combining screens with bypass facilities, 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 & 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 (Larinier, 2001). Screens should be situated where water is diverted from a river and not within the extraction channel itself as fish may prove reluctant or unable to return to the river. Although, there have been good experiences with intake channels that are fitted with a bypass system. In these cases this approach showed to be more successful then screening at the point of diversion.

LIFE Integrated Project Freshabit Mustionjoki River

The main objective of Freshabit LIFE IP project (2016-2022) is to improve the ecological status of water bodies in the Natura 2000 network in Finland. During the project six fishways will be built and one dam removed to restore connectivity for migratory salmonids. A) As part of the project a telemetry survey is carried out in the Mustionjoki River. Fish are being stored in a fish cage shown with the Billnäs-Dam in the background. © Luonnonvarakeskus. B) Further upstream is the Mustio Dam. © Luvy ry/Juha-Pekka Vähä. C) One of the key species is the freshwater pearl mussel, which needs juvenile salmonids as the hosts for their parasitic glochidium larvae. ©Jari Ilmonen.

Further information: www.metsa.fi/web/en/freshabit







ΓΧΔΜΡΙ Ε

Developing test guidelines for fish-friendly pumps and turbines

Authors:

Peter Paul Schollema¹, Marius van Wingerden², **Rik Beenties³ & Jos de Biil⁴** Organisations: Dutch Water Authorities 'Hunze en Aa's, ²Scheldestromen, ³Hollands Noorderkwartier & ⁴Delfland The Netherlands

Country:

INTRODUCTION

A large part of The Netherlands is located beneath sea level. An impressive system of sea defence walls, inland levies and more than 5,000 large pumping stations ensure the safety of the people who live in these polders, drained areas that lie below sea level. This safety system for people comes with two unwanted side effects; 1. migrating fish trying to enter pumped freshwater systems are partially excluded by the pumping stations and 2. outward migrating fish run the risk of being damaged by the pumping stations.

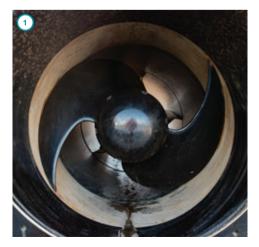
This article will focus on the second problem. Typical species that live in these polder systems, for example the European eel (Anguilla anguilla) need to get past these pumps if they are to return to their breeding areas. Over the last decade there has been increased interest in adapting and designing new pumps to make them more fish-friendly. The European Water Framework Directive and the European Eel Directive and associated national regulations have focused attention on these matters.

WHAT DID YOU DO?

In recent years, pump manufacturers in The Netherlands have made large steps forward in the development and production of fish-friendly pumps. In 2006 there were hardly any such pumps available, but nowadays almost all large manufacturers have one or more prototypes

FISH-FRIENDLY PUMPS

- 1 New fish-friendly Pentair Fairbanks Nijhuis blades at pumping station C. Mantel in Schardam. The Netherlands, © Rik **Beentjes**
- 2 Installation of a fish-friendly Fishflow Archimedean screw at pumping station Hoekpolder, Rijswijk, The Netherlands. © Jos de Biil
- 3 On the island of Texel all pumping stations will be fitted with fish-friendly Bosman Vision pumps. The photo shows construction works at pumping station De Schans, Texel, The Netherlands. © Klaas Sjouke de Boer
- 4 Testing pumping station Ennemaborgh which is fitted with two fish-friendly Landustrie Archimedean screws. Winschoten, The Netherlands. © Peter Paul Schollema
- 5 Fish-friendly Flowserve pump, pumping station Berkel, municipality Lansingerland, The Netherlands. © Jos de Bijl

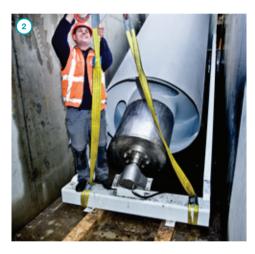


available. Most of these have now been tested, but usually under different test circumstances and/or with different parameters, e.g. the number of fish used or the size of the fish.

Manufacturers and water managers both need reliable information in order to compare pumps during technical assessment and in tender processes. This makes it more important to test these fish-friendly pumps with a standardised test. In 2016 a consortium from 26 different organisations, including water managers, ecological consultant companies, pump manufacturers from The Netherlands and Belgium and universities started a process with the NEN (Netherlands Standardization Organisation) in Delft to work on a standardised testing protocol for fish-friendly pumping stations and turbines (NEN, 2018 in prep).

HOW DID IT WORK OUT?

The NEN 8775 standard provides step by step information on how to undertake a standardised test of a fish-friendly pump or turbine. It speci-









fies subjects such as the equipment needed, test setups, quantity and sizes of fish to be used, damage classification, and quantification of the damage caused. The basis of the protocol is socalled "forced transit" tests. Field testing with the use of naturally available fish populations is another possibility, but experience from earlier testing was that there is not always enough fish (species and size-range) available to pass through the pumping station, making these more natural tests less favorable. Timing is also an important factor; a large proportion of silver eel will pass in a short timeframe during high discharge events, which makes the timing of field tests a challenge.

Information collected from these tests will be used to classify the tested pump. Data will also

be used to further improve and fine-tune the damage calculation model that is also part of the testing protocol. In late 2017 the draft protocol was finished and, after public consultation it will be finalised in 2018.

LESSONS LEARNED

The development of this testing protocol has proven to be a challenging process. Bringing together the knowledge and opinions of a wide range of professions such as pump-engineers, biologists, scientists and standardisation specialists has resulted in many interesting meetings but also delivered a well discussed (draft) protocol. We are confident that another important step has been taken in the process of solving the fish safety problems that come with pumps and turbines.

PUMPING STATION ENNEMABORGH

Set up of storage basins to carry out a so called "forced transit" test to determine if the installed Archimedian screws are fish-friendly. © Peter Paul Schollema



Bypass systems

In addition to screening to prevent fish entrainment into extraction 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 outtake, the proportion of flow within and 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 halt extractions 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 based on environmental cues. 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. This is likely to be river, species 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 (Bruijs, 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 only this approach.

Other possible technical warning systems consist of surveillance by underwater cameras, or fish detection by sonar. There are turbines proven to be relatively friendly to fish, which might reduce passage mortality at hydropower sites. 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.

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 trucking, and then to release them in a safe location 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. 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).

8.5 STEP 3: CONSTRUCTION & MAINTENANCE

8.5.1 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)?

ΓΧΔΜΡΙ Ε

The Forest Service Stream Simulation Approach to ensuring aquatic organism passage at road-stream crossings

Authors:	Nathaniel Gillespie ¹ , Daniel Cenderelli ² , Robert Gubernick ³ , Mark Weinhold ⁴ & Joseph Encinas ⁵
Organisation:	¹ USDA Forest Service, Fisheries Staff, Washington, DC; ² USDA Forest Service, National Stream & Aquatic Ecology Center, Fort Collins, CO; ³ USDA Forest Service, Region 9 Technical Services Team, Duluth, MN; ⁴ USDA Forest Service, White River National Forest, Glenwood Springs, CO; ⁵ USDA Forest Service, WFWARP Staff & Washington, DC.
Country:	United States of America

ountry:

Aquatic organism passage (AOP) at road-stream crossings has been the subject of engineering, fisheries, hydrology, and wildlife specialist concern for many decades across the United States. Hundreds of thousands of road-stream crossings exist in the USA and fragmentation of aquatic habitat from these crossings is a well-documented impact to salmonids and aquatic diversity. The USDA Forest Service (USFS) manages over 370,000 miles of road across 193 million acres of National Forest and Grassland which contain an estimated 40.000 road-stream crossings (RSC). Typically 50% to 90% of these crossings are barriers to fish and other aquatic organism migrations at some life stage. Conventional, hydraulic designs of RSC are typically much narrower than the natural channel, causing fragmentation of aquatic habitat and biota over time by impeding the upstream migration of fish and other aquatic organisms. Additionally, undersized RSC structures can clog with sediment and wood and can catastrophically fail during flood events,

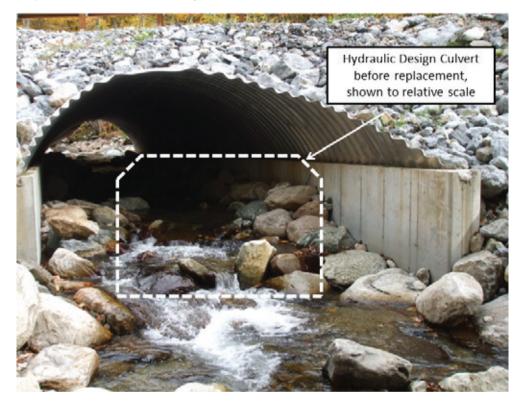
causing significant damage to transportation infrastructure and property and loss of life.

The USFS developed and uses the stream simulation method as its preferred approach across its 154 national forests and grasslands for RSC on fish-bearing streams. This design approach is integral to meeting the intent of the Federal Clean Water and Endangered Species Acts. Stream simulation is a geomorphic, engineering, and ecologically-based approach to designing RSC that creates a natural and dynamic channel through the structure that is similar in dimensions and characteristics to the adjacent, natural channel. This in turn allows for unimpeded passage of fish and other aquatic organisms at all life stages and conveys water, wood and sediment through the structure during flood events

The replacement structure type and size, which can include a bridge or variety of culvert configurations, are determined by the bankfull

FIGURE 1

Completed Stream Simulation Design. Showing to scale the undersized, hydraulic design culvert that it replaced, Green Mountain and Finger Lakes National Forest, Vermont. © USDA Forest Service.



widths and scour depths of the adjacent, natural channel as well as any projected vertical and lateral adjustments of the stream over the service-life of the structure. As a result, stream simulation structures are able to convey water, sediment, and wood through the structure for flows well in excess of the 100-year flood.

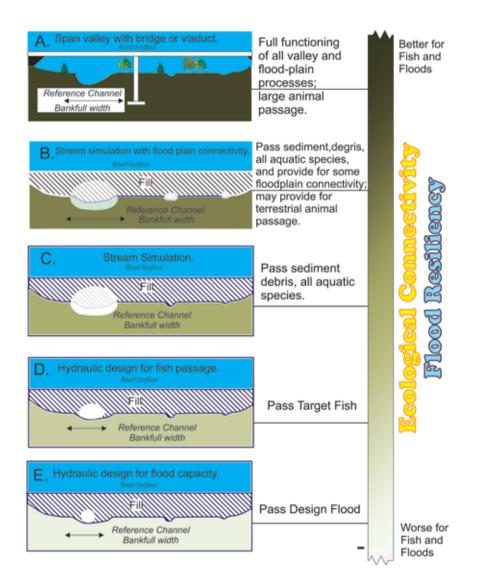
Stream simulation designs provide both increased ecological connectivity and infrastructure flood resiliency compared to conventional, hydraulic designs of RSC. Floodplain relief culverts can be installed through the road prism to facilitate partial flow continuity for wider floodplains. The replacement structure type (bridge or culvert) and size are determined by reference channel dimensions and estimated vertical and lateral adjustments over the service life of the structure.

Restoring aquatic connectivity is a top priority for the Forest Service, and since 2008, USFS and hundreds of partners have mitigated approximately 1,350 RSC for aquatic organism passage. Stream simulation costs are typically 10% to 30% greater than hydraulic culvert designs in year 0, however, avoided costs such as averting catastrophic failure and reduced maintenance, and a functional life span of an additional 25 to 50 years compared to hydraulic designs are increasingly demonstrating the long-term economic benefits of stream simulation designs.

>>EXAMPLE

FIGURE 2

An ecological connectivity and flood resilience continuum for different design approaches at roadstream crossings. The stream-floodplain simulation design (A) provides passage for all aquatic and terrestrial species at all flow levels and all geomorphic and ecological processes, and is flood resilient. The stream simulation designs (B and C) provide the majority of geomorphic and ecological processes, are flood resilient, and pass all aquatic species. The hydraulic designs (D and E) only provide for partial functioning of stream processes, alters downstream conveyance of some floodwaters, sediment and woody debris during high flows, and impede passage of most aquatic species for most flows, consequently providing low ecological connectivity and flood resiliency. © USDA Forest Service.



If a fish passage fascility has been identified as the solution, then the following should be considered:

- 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 or dam?
- Is the pass co-located with any other discharge (e.g. hydropower discharge) that could maximise attraction?
- Is the turbulence in the pass within acceptable limits for all target species?
- Will the fish pass be passable for each of the target species in the appropriate season?
- Is the fish pass large enough to accommodate expected future peak migrations of the target species?
- Are there sufficient arrangements to exclude and remove debris especially during migration periods?
- · Can the fish pass be easily accessed for

clearing of debris and maintenance?

- 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. to prevent migrating fish from being swept downstream?
- Have provisions for monitoring been built into the structure (e.g. power, installation points), and a system to review, and adapt design or operations been included?

And finally,

- · Is the facility safe for all who visit it?
- Can the facility be designed to allow the public to visit?

Downstream facilities

The proposed design of a downstream facility should also be carefully checked prior to construction:

Maintenance

The regional Water Authority Hunze & Aa's hydrologist explains the maintenance preferences for this fishway. © Herman Wanningen.



- 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 extraction management systems?
- 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?
- 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?
- 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 they have 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 to avoid injury to fish on rocks or structures below and to reduce the risk of predation by birds or fish?

8.5.2 Operational & 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 gravel 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 and economically 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.*, 1998; Turnpenny, *et al.*, 2005).

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. Maintenance is best done as part of a structured inspection programme or protocol that defines the times when the facility must work. In Finland fish passes are closed during the winter, or the amount of water passing through it 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 so they are ready on time. The intensity of maintenance will differ per site, depending on local circumstances, and this will be readily identified following operational experience and an objective risk assessment (Armstrong, et al., 2010) and monitoring. 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 <u>essential</u> that operator health and safety issues are taken into account.

CHAPTER 9 MONITORING AND EVALUATION

This radio telemetry study is conducted to evaluate solutions that safeguard the downstream migration of adult eels in the river Ätran (Sweden). © Herman Wanningen.

INTRO

Over the last few decades many fish passage solutions have been constructed all over the world. It is of great importance that these structures are well monitored and evaluated. Results can be used to fine-tune the performance of the specific fishways studied, but they also provide valuable input to improve design criteria for future projects. replace: Despite the overwhelming need for these data, good monitoring results is absent in many cases (Silva, et al., 2017). This is because of the cost of effective monitoring and the false perception by funders that this has little benefit. It is essential that effectiveness or lack of effectiveness is demonstrated so that environmental outcomes can be confirmed, and performance and learning optimised. The importance of monitoring and evaluation is demonstrated by a study in the USA that reviewed 19 monitoring programmes involving 26 species. It was concluded that that in most cases existing data was inadequate to

reliably inform design recommendations (Bunt, et al., 2012 & 2016).

Monitoring of fishways is vital to confirm a) that the hydraulic functioning of the fishway meets the design specification for a diversity of flow conditions, b) the location provides adequate attraction flow so that fish find the entrance (this should be for up- and downstream passage of all species that naturally would move through the dam site), and c) to evaluate the overall efficiency and, in some cases, the consequences for fish populations and passage time or delay. In general, monitoring contributes to an important learning process to improve future designs and to detect shortcomings and positive aspects of facilities. It is also important to learn how well fishways function so that we may confirm that management systems are optimal and progressively improve our designs.



9.1 MONITORING AND EVALUATION OF FISH MIGRATION

Despite the large body of literature covering design criteria for fishways and other facilities, several important information gaps exist including the reasons for poor efficiency of some structures and how refinements can be made to optimise their performance. One reason for such knowledge gaps is the lack of a standardized terminology and procedure for fish passage evaluations, which is the main driving force behind the recent initiative "Guidance for assessing the efficiency and related metrics of fish passage solutions using telemetry" (CEN/TC 230, 2018 in prep.), Studies that examine biological aspects of passage, such as the behaviour and swim capacity of target fish species, and the effects of different hydraulic environments on them, are necessary to expand the knowledge base of fishway science. In this context, Castro-Santos, et al., (2009) suggests a framework for evaluating fishways, highlighting a set of biologically relevant performance parameters and hydraulic covariates.

The combination of both hydraulic engineering and design with behavioural and ecological aspects in fish migration studies have become much more common and more adept over the last few years. Combining information from different fields of expertise gives a good opportunity for better understanding of fish behaviour and design requirements at a diversity of local sites. For example, studies where silver eel behaviour is linked to hydraulic conditions either at a turbine intake (Piper, *et al.*, 2015) or an outlet of a water treatment plant (Winter, *et al.*, 2011), will help managers optimise the design of safe and effective passage facilities.

To understand the mechanisms of migrations and to mitigate human impacts on fishes, interdisciplinary studies listed above should preferably be combined with experts in telemetry, fish behaviour, physiology, functional genomics and experimental biology (Cooke, *et al.*, 2008). An interdisciplinary approach allows fish passage scientists, engineers and biologists to address new questions regarding the consequences and mechanisms of passage, and to resolve persistently difficult issues such as attraction to fishway entrances. 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, although some work has been done regarding migratory cues and swimming abilities (e.g. Andrade e Santos, 2012; Freitas Duarte, 2012), a lot remains unknown for most of the fish species living in these regions.

9.2 DEFINING EFFECTIVENESS AND EFFICIENCY

Key questions should be addressed that focus on the effectiveness, efficiency and hydraulic functioning of fish passes that are defined by the target species and will differ for the upstream and the downstream facilities.

The aforementioned ongoing work in Europe (CEN/TC 230, 2018 in prep.) uses the following definitions for effectiveness and efficiency. It is noted that fish passes, fish passages and fishways are all referred to as "Fish Passage Solutions" (FPS). This document is not an European standard and it is a draft that can be subject to change before the final version is published.

FPS <u>effectiveness</u>: An assessment or count of the number and type of fish successfully negotiating the FPS in relation to the fish community present.

FPS <u>efficiency</u> (overall): The percentage of available fish attempting to pass an impediment(s) that find, enter and successfully negotiate, the FPS. This encompasses attraction, entrance and passage efficiencies.

At a more detailed scale, FPS overall efficiency can be split into partial definitions:

· FPS attraction efficiency: The percentage

EXAMPLE

Large reservoirs may act as barriers to fish migration in South America: the case of Três Marias Reservoir

Authors:

Organisation: Country: João de Magalhães Lopes, Carlos Bernardo Mascarenhas Alves & Paulo dos Santos Pompeu Federal University of Lavras Brazil

INTRODUCTION

The Três Marias Dam is located in the upper São Francisco River, Brazil and impounds a large reservoir with a surface area of 1040 km². Migratory fishes are still found upstream and downstream of the reservoir, in areas with extensive remnant lotic habitats. Migratory characteristics of the Curimatá-pioa (Prochilodus costatus), an endemic species of the basin, were evaluated in order to assess the need for installation of a fish passage in the dam. This genus is of great ecological importance with a crucial role in nutrient cycling, and is also one of the most fished species in South American basins (Castro & Vari, 2004). Prochilodus species undertake long upstream reproductive migrations to release eggs and larvae that are carried downstream to the rich flood plains formed by river flooding. After spawning, the adults return to their feeding sites, repeating this cyclic movement for several years (Carolsfeld, 2003).

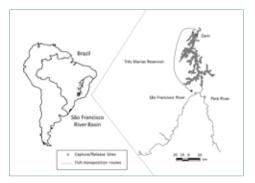
WHAT DID YOU DO?

We tagged 402 individuals with radio transmitters during 2014 and 2015 in three different scenarios:

- 1 First, we evaluated the migration of individuals (177) from a population inhabiting a free-flowing river stretch (about 400km) located upstream of the reservoir;
- 2 Secondly, we evaluated the migratory behavior of individuals captured from those concentrated downstream of the dam and manually relocated into the reservoir (80) and finally;
- 3 a sample was relocated to the same river stretch upstream from the reservoir (145).

IGURE 1

Map of the study site.



HOW DID IT WORK OUT?

We observed distinct behavioral patterns in the three groups:

1 In the population tagged in the free-flowing stretch, some of the fishes remained in their feeding sites during all year, apparently not reproducing, whilst the remainder migrated 250 to 350 km upstream to reach their reproductive sites. The reproductive migration occurred shortly after the beginning of the rainy period (October and November), and spawning occurred when rainfall intensified (November to January). Precipitation causes alterations in water flow and quality that triggers migration and spawning. The return of these fish to their feeding sites occurred from December to May.

Fishes from the two other groups presented different behaviors.

- 2 Those transposed to the reservoir generally did not move more than 20 km from their release point. The lentic environment is structurally very different from the river and the relocated fish did not have the capacity to navigate through the reservoir. Only 5% of these individuals found a tributary. This indicates that a large reservoir may act as a behavioral barrier for adult migration, in addition to interfering with egg and larvae transportation as suggested by Pelicice *et al.*, (2015).
- 3 Fish relocated to the free-flowing river stretch upstream of the reservoir also presented abnormal behavior. They showed erratic movement patterns, swimming upstream and downstream several times in a short interval. They seemed incapable of recognizing marks and migratory stimuli in the new environment, as if they were lost after released.

LESSONS LEARNED

 Large reservoirs seem to work as barriers to the upstream and downstream movements of migratory fish. Passages conducting fish

STUDY SITE

A) Três Marias Dam; B) São Francisco River upstream theTrês Marias reservoir.





from rivers to such environments may not be effective if individuals are then not able to find suitable sites for reproduction.

- Even the transposition of South American migratory fishes to free-flowing river stretches upstream of impounding reservoirs may be inefficient if they are then not capable of recognizing the environmental and geographical cues required to subsequently perform migration and spawning.
- Our results indicate the need to invest in strategies firmly based on the biology and ecology of South American migratory fishes. Solutions already adopted for species from other continents may not be effective for this group, due to differences in behavior and life cycles characteristics and the larger size of many South American reservoirs.

ΓΧΔΜΡΙ Ε

Monitoring of fish passage in the Belo Monte megadam, Amazon basin, northern Brazil

Authors:

Lisiane Hahn¹, Hugo Marques¹, Jonas Kilpp¹, Marina Granai¹, Alexandre Marcal², Leonardo Nunes¹, Leonardo Machado¹ & Luís Fernando da Câmara¹ & Taise Miranda Lopes¹ Organizations: 1Neotropical Consultoria Ambiental & 2Ecofish Research **Country:** Brazil

PHRACTOCEPHALUS HEMIOLIOPTERUS © Neotropical Consultoria Ambiental.



INTRODUCTION

The Amazon River basin, the largest and one of the most biodiverse in the world, is today facing an unprecedented boom of hydropower dam construction, in common with other river basins in tropical regions (Winemiller et al., 2016). Migratory fish species are most affected by impoundments and it is a fundamental requirement to assess the feasibility of installing fish passages. However, they can be unsuccessful or even harmful to some fish assemblages (Pelicice & Agostinho, 2008). Located on the Xingu River, a unique ecosystem with long distance migratory fishes as well as species highly adapted to live in zones with rapid flows, the Belo Monte hydropower complex consists of two dams and a shunt channel. Its design makes it the third largest in the world with an installed capacity of 11,233 MW. The Belo Monte fishway is 1.2 km long and up to 15 m in depth and started to operate in February 2016.

WHAT DID YOU DO?

A series of studies to investigate fish movements and the efficiency of the recently opened fishway was conducted in Belo Monte. The requirement was to assess if migratory fish species could overcome the Volta Grande (Big Bend), a natural barrier of 100 km of rapids and waterfalls. Therefore, 400 fish were tagged with combined acoustic and radio transmitters (CART) before the dam closure and monitored along an 800 km length of river. Questions regarding attractiveness. efficiency and selectivity of the fishway were investigated as soon the fishway started operation, using Radio Frequency Identification (RFID), video recording (installed in two windows in the fishway), fish sampling downstream and inside the fishway and fish tagging with hydrostatic tags.

HOW DID IT WORK OUT?

The fish movement results prior to the dam closure demonstrated that Volta Grande did not represent a natural barrier for *Phractocephalus hemiliopterus* (Pirarara), *Pseudoplatystoma punctifer* (Surubim) or *Brachyplatystoma filamentosum* (Filhote).

In the fishway study, the preliminary results with the three techniques combined (RFID, video recording and sampling) identified the presence of 124 species, some of which were unique to each technique (7 through video recording and 85 by sampling). Amongst this set of species, 45 species were present in the fishway and 41 of these are short or long distance migratory species. PIT antennas were installed in three transects inside the fishway (two in the medium stretch and one in the upper stretch). Fish sampling was carried out in the fishway and downstream from the dam. A total of 164 individuals from 22 species belonging to four orders and ten families, including migratory and sedentary species, were tagged with PIT tags. Of these, 146 were captured and released inside the fishway (between transects in the middle stretch) and 18 downstream of the dam. During the five months of monitoring, 108 individuals (66% of the tagged) from 20 species were recorded, all captured and released inside the fishway.

There is three main patterns of displacement inside the fishway: the "expected/desired" behavior: firstly after releasing inside the fishway, the individual descends and in a short time retake the upstream movement. Second, the individuals explore the fishway region, being recorded several times in the antennas of the transposition channel. At least, the fish released inside the fishway returns to downstream and leave the system, not being registered again.

The combination of different monitoring techniques allowed us to determine precisely the ichthyofauna present in the fishway, to develop an understanding of behavior and to generate ecological and biological hypotheses for the next steps of the monitoring program.

LESSONS LEARNED

The information gathered so far demonstrates the importance of using different techniques and methodologies to identify fish movements downstream and upstream of the dam and in the fishway itself. The results are crucial for the understanding of fish behavior and management of migratory species in the Amazonian rivers affected by dams.

UPSTREAM STRETCH OF THE BELO MONTE FISHWAY AND EXIT CHANNEL TO THE RESERVOIR © Neotropical Consultoria Ambiental.



of available fish that are attracted to the FPS entrance;

- <u>FPS entrance efficiency</u>: The percentage of fish attracted to the FPS entrance that subsequently enter;
- <u>FPS passage efficiency</u>: The percentage of fish entering the FPS that successfully negotiate and exit the FPS.

The <u>effectiveness</u> of a pass is a qualitative description of FPS performance. Effectiveness depends on attractiveness and passability for each target species, and the population and ecological outcomes achieved.

GENERAL QUESTIONS FOR EVALUA-TING FISH PASSAGE FACILITIES:

- Which species need to use the facility?
- Do all target species (in all relevant life stages) use the facility?
- Do the facilities favour one size life stage or species over another?
- Does the facility have a habitat function for target species?
- Are there adverse effects of predation that are caused or amplified by the facility (e.g. invasive blue catfish moving into the fish ladders on the James River and growing too fat to leave)?
- What influence does the facility have on the dynamics of each relevant fish stock?

The <u>efficiency</u> 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 (or upstream moving down) of the obstruction and motivated to pass, that enters and successfully moves through the facility.

Cumulative effects almost always occur when fish stocks must overcome multiple obstacles in a river. Since each FPS is likely to have different efficiency ratings, the impact of each barrier in a series can be highly variable and have unintended negative consequences on fish. This has compounding effects as there can be attrition of fish approaching a FPS due to loss along the way, injury to fish, exhaustion, and even just lengthy delay causing fish to abandon migration. This has additional impacts for species that are depend on abundant schools to motivate migration and spawning. Evaluations should set quantitative passage effectiveness goals for each target species. These are often set as a percentage of the population that should pass and the acceptable migration delay. For anadromous species such as salmon, passage upstream of the whole population in a way that is safe, timely and effective should be the goal for any obstacle located downstream of spawning grounds. If appropriate spawning grounds are located below the obstacle, then performance goals can be less stringent for some target species. This is also the case for potamodromous species, where effectiveness is judged by the proportion of the available stock that can safely pass in both directions.

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 be many unsuccessful attempts at passage. Efficiency is a better descriptor of performance, as this is a measure of the proportion of the total available fish coming towards a dam that wished to pass the obstacle and that were able to do so. It is usually further defined not just in numbers, but also the time (minimizing delay), and condition of fish (safety) that is observed.

9.3 CHOICE OF MONITORING METHODS

Methods for monitoring upstream and downstream migration can be capture-dependent and capture-independent methods. Capture dependent techniques (efficiency studies) 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 (effectiveness studies), are generally more effective but also more expensive, consisting of visual observations and remote sensing techniques.

9.3.1 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.

<u>Direct techniques</u>, such as trapping within or immediately upstream of the fish pass, are capture-dependent methods that give <u>indicative</u> <u>information</u> 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, if that individual fish uses the 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. Often fish are captured in a trap at the top of a lift or ladder, tagged, and then released downstream. Efficiency is determined by the percentage of those experienced fish that re-ascend the FPS and are counted again at the top. This method is repeatable and common, however, it does not give an indication of how many of the fish approaching the fishway do not, or cannot enter it. By monitoring fish experienced with fish passage already (they made it to the top once) and not naïve fish, this method is necessarily biased.

Indirect methods such as simple visual inspections, video monitoring, automatic counters (resistivity or 'Vaki') and techniques including splitbeam and DIDSON sonar video cameras 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 can be appropriately evaluated and used in the most effective way.

Fish counters can provide very good quantitative data on the numbers of fish ascending and de-

scending a fish pass. They generally require relatively non-turbulent water and low debris loads 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 the selection of one verses another depends on many factors. These include the size of the pass, the clarity of water during migration, the inclusion of a counter installation (space, electricity, communication hook-up) during design and construction of the fish pass, and the financial and staff resources available. The choice of counter type also depends on the behaviour of the target fish species, the required level of accuracy and species discrimination. Depending on your goals for monitoring you should consider reliability and precision, the potential for species identification, and potential for individual fish measurement. Some systems are available "off the shelf", for example the Icelandic Vaki system (www.vaki. is) or the FishCounter (www.visadvies.nl). There are many custom-made systems available often using cheaper modular deployments of underwater cameras and lighting systems, but these may be less reliable, or the data less easily interpreted, and they can prove to be more labour-intensive.

Much more informative data may be obtained using more complex radio telemetric tracking programmes such as radio, acoustic or PIT (Passive Integrated Transponder) tagging. From these systems valuable information on individual fish behaviour in the vicinity of the pass and timing during passage itself can be derived. Commercially available radio telemetry systems are available, where tags can be implanted in fish or placed in the stomachs (gastric tags) of larger salmon. Another technique that can be used is external attachment. Tags transmit coded signals to receivers either continuously or at specified intervals. Carefully placed receivers can reveal when fish approach a fish pass, the timing and movement of a fish searching for an entrance, and how some fish may 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 a location.

ΓΧΔΜΡΙ Ε

Passage of small juvenile fish in Australia

Authors:

Country:

Tim Marsden¹, Martin Mallen-Cooper² & Ivor Stuart³

Organisation: ¹Australasian Fish Passage Services, ²Fishway Consulting Services & Charles Sturt University & ³Kingfisher Research & Arthur Rylah Institute Australia



Within Australia, catadromous, amphidromous and potamodromous species are well represented, forming up to 80% of the freshwater fish fauna in some regions. This results in abundant small juvenile fish migrating either from marine to freshwater habitats, or along rivers. Due to their small size (15-50 mm long), their swimming ability is limited.

juvenile fish in prototype fishways has been done in the laboratory and field sites (e.g. Marsden et al., 2017). Turbulence is now known to be a key design aspect for small fish (Mallen-Cooper et al., 2008), while small Denil fishways are ineffective for small fish

Solutions include: dedicated fishways for small fish, dual fishways (separating small and large fish passage), or combined fishways (passing small and large fish) (Baumgartner et al., 2014). At sites with variable headwater, low-turbulence

SOLUTIONS

Research into the swimming capacity of small

JUVENILE EMPIRE GUDGEONS

Large numbers of juvenile empire gudgeons (12-20 mm; Hypseleotris compressa) accumulating below the Fitzroy Barrage (QLD) prior to the installation of a suitable cone fishway. © Tim Marsden.



FISHWAYS

Fishways used for providing passage of small and juvenile fish species in Australia. A) low gradient vertical slot fishway, Sheepstation Creek (QLD), B) rock ramp fishway, Moores Creek (QLD) and C) concrete cone fishway, Fitzroy River barrage (QLD). © Tim Marsden.



(25-30 W/m⁻³ [Cd 0.7]) vertical-slot fishways and fish locks are used; either with small pools dedicated for small fish or larger designs to also pass large fish. At sites with small headwater fluctuation, rock-ramp fishways and cone-baffle fishways are widely used, as well as roughened sides of culverts (Amstaetter *et al.*, 2017).

The vertical-slot and cone-baffle fishways have head losses between pools of 50-100mm and average turbulence levels of 30 W/m⁻³. They have been effective (95% passage of abundance and length range) in passing juvenile fish down to 20 mm (Bice *et al.*, 2017). Applying 80mm head losses in cone fishways and an average turbulence 15 W/m⁻³ has enabled 12mm fish to ascend, as well as a high biomass (Marsden *et al.*, 2017). Rock-ramp fishways have been effective in passing 10mm fish, as they have high levels of roughness, providing effective boundary layer hydraulics.

The small fish locks have been effective because the entrance velocity and turbulence can be reduced to suit the swimming ability of the fish. However, maintenance has been higher in fish locks. Rock-ramp fishways sometimes need repair after floods, while vertical-slot and cone fishways have the lowest maintenance. In all these fishways for small fish, *passage efficiency* is often high but the low turbulence results in low discharge and there can be poor *attraction efficiency* if adjacent riverine passing flows are high.

WHAT ARE THE KEY DRIVERS?

Maintaining and restoring biodiversity is a key driver. Especially vulnerable are juvenile catadromous and amphidromous fish at tidal barriers which are highly susceptible to predation. Larger migratory species support valuable recreational fisheries and small commercial fisheries; all are dependent on a healthy diverse ecosystem, which requires the passage of small-bodied fish.

Legislation in all states now ensures that suitable passage is considered at all new barriers and is generally applied. However, existing barriers remain the most common and significant issue.

LOOK TO THE FUTURE

Further research is needed on passing a high biomass of juvenile fish, fishway capacity and the energetics of small species in long fishways; as well as establishing performance indicators and standards for *attraction* and *passage efficiency* that link with sustainable populations.

SPECIES EXAMPLE

The mighty stickleback, small but tough and versatile

 Author:
 ir. J.B.J. Huisman

 Organisation:
 Van Hall Larenstein Applied Sciences University

 Country:
 Netherlands



GEOGRAPHICAL DISTRIBUTION

The three-spined stickleback (*Gasterosteus aculeatus*) is distributed in coastal regions throughout the northern hemisphere and is found in multiple morphological forms and in a wide array of habitats. They can be found in marine, brackish water and fresh water bodies (Arai *et al.*, 2003). Most sticklebacks migrate over small distances but the migratory diadromous form of the species has been found up to 500 kilometres away from the closest land.

LIFECYCLE OF THE DIADROMOUS STICKLEBACK

Diadromous three-spined stickleback spawn in fresh to brackish waters in winter and spring. When the spawning season begins, the males are the first to migrate and become territorial, building nests from plant material for the eggs and larvae. After fertilising the eggs the male takes care of its offspring until, after a few months, the young fish migrate to sea during autumn. There are many aspects of their life cycle which remain unknown, for example most aspects of the marine phase, including preferred habitat, and mortality rates are unclear.

HUMAN IMPACTS

The shallow coastal waters are important nursery and spawning areas for sticklebacks. However various factors including land recovery and construction of dikes, dams, sluices and pumping stations in coastal zones make it difficult for diadromous sticklebacks to migrate to and from their spawning areas. In addition habitat degradation of the spawning areas, due to channelization and dredging, may reduce spawning success and survival rate of the young sticklebacks.

POSSIBLE SOLUTIONS

In order to facilitate stickleback migration, management of tidal water infrastructure has to be altered and/or fish passes have to be build. In the Wadden Sea (Northwest Europe) fish passes have been built to accommodate stickleback migration (Huisman, 2017), however in some cases fish passes can only function for short times within the tidal cycle. Even fish passes may therefore prove to be only temporary and partial solutions at key migratory pinch points.

DRIVERS FOR THE IMPROVEMENT OF STICKLEBACK STOCKS

There is no commercially fishery for stickleback, however they may play an important role in coastal ecosystems. Sticklebacks are considered to be an important food source for spoonbills (*Platalea leucorodia*) in the Wadden Sea area.

The design and construction of (tidal) fish passes in Europe is mainly driven by the Water Framework Directive (European Commission, 2000). In addition, sticklebacks are often considered to be a key species driving fish pass design as they represent the smaller diadromous species.

LOOK TO THE FUTURE

It is important to further understand diadromous stickleback migration in marine and tidal areas, and there is a great need to gain information on the life-cycle of sticklebacks. It is important to determine the drivers and cues determining and influencing stickleback migration and if these are adequately considered in anthropogenic altered situations. As the stickleback is a species present in large parts of the Northern Hemisphere, they may prove to be a key species in understanding diadromous migration and how to facilitate diadromous migration in coastal areas.

OVERVIEW OF STICKLEBACK RESEARCH ALONG THE DUTCH WADDEN SEA COAST

A) Ebb tide at Spijksterpompen in the Wadden Sea, © Jeroen Huisman. B) Three-spined sticklebacks caught during research in the Wadden Sea, © Jeroen Huisman. C) Students of Van Hall Larenstein Applied Sciences University involved in fish migration research at the sea sluices of Nieuwe Statenzijl, © Peter Paul Schollema.







FISH COUNTERS

Jan H. Kemper (VisAdvies BV, The Netherlands)

Fish passages come in many varieties. Their functionality is very variable, and evaluation is therefore of great importance. For a long time evaluation in The Netherlands was conducted with fyke nets at the exit of the fish passage structure. However recent technological advances have offered new possibilities to study fish migration in much more detail. Perhaps the most popular approach has used fish tagged with Passive Integrated Transponders (PIT). The big advantage of this technique is that individual fish can be electronically detected at both the entrance and exit of the fish passage. An alternative approach is the *resistivity fish counter*.

Mobile counting unit

A) Counting electrodes; B) Camera housing; C) Light; D) Camera.



Counting unit on crump weir



Fish Counter

The fish counter technology uses the detection of a subtle change in electrical conductivity that is induced by a fish as it passes over an array of 3 parallel electrodes. Conductivity of a fish is different to that of the water and this triggers disruption of the electrical Wheatstone Bridge between the electrodes. Detection includes the swimming direction of each fish, and the size of the electrical current gives an indication of the fish length. In contrast to the PIT technology, fish do not need to be caught, tagged and released again. This means that all passing fish can be detected. The electronic detection can be used to trigger a submersible camera to identify the fish species. Resistivity fish counters have been used in many locations in the UK on crump weirs to monitor salmonid migration in small rivers. In 2010 the technology was introduced to the Netherlands where small mobile units are being used. The current focus has been on short term studies (usually one season) to evaluate the efficiency of fish passages.

An important conclusion from the studies with these systems is that monitoring of fish migration with fyke netting may become obsolete in situations where a Fish Counter can be applied. In some trials where fyke nets and a counter have been compared, it became clear that fykes can be very selective for small fish. In clear water it seems that large fish are often very cautious and it is hard to encourage them to enter the last chambers of the fyke. As with the PIT tag technology, the fish counter offers the possibility to monitor a fish passage at both sides. Fish observed at the exit of a passage may suggest that it works well, however this can only be confirmed by comparison with the numbers of fish that enter the migration facility.

Whichever approach is used, the use of these technologies is giving better insight into the migratory behavior of fish.

Perch (Perca fluviatilus)



Asp (Aspius aspius)



PIT-tags have been developed as miniature transponding tags for fisheries studies. They emit a signal when the tag comes within range of a detector and is interrogated, for example when a 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 & Breukelaar, 2001).

Radio, acoustic and PIT tags have all developed a lot over the last decade and today they are available in a wide range of sizes depending on battery size and lifetime. This means that tags can now also be deployed during studies with very small fish.

Telemetry information can be used in many ways, for instance to collect detailed biological information, but also to adapt management of fish passes and for improvement of the design of nature-like fishways.

Acoustic tags can be used with networks of receivers to provide detailed 3-dimensional information on fish location, although such systems are comparatively complex and are sensitive to aerated water and turbulence.

Sonar techniques, such as the ARIS system (next generation DIDSON), Simsonar or blue view can be extremely powerful in fisheries studies, however clear criteria for deployment must be followed. These systems can detect fish in video and in three dimensions at a range of up to 40 m (more in certain circumstances) and can provide data on the abundance, swimming direction and depth of fish.

However, they usually cannot be used in horizontal deployments at depths less than 2 m and they are very sensitive to entrained air, which is of course common at many fish pass entrances. They cannot provide information on fish species but with supplementary information such as seasonality and size of fish this can in some cases be interpreted. Supplementary netting for instance 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

Acoustic tagging of Atlantic sturgeon

Maine researchers measure the fish and implant an acoustic tag before releasing this Atlantic sturgeon. Dozens of shortnose and Atlantic sturgeon are being tracked. They were found in larger numbers in the Penobscot River than expected. Both species benefit from mainstem dam removals in 2012 and 2013. © Josh Royte.



Installing telemetry equipement

Installation of a PIT antenna at the fishway Wedde in the River Westerwoldse Aa, Netherlands. © Peter Paul Schollema.



flows. More intensively studied sites might be used to 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.

Efficiency

Ideally efficient fish passes enable the passage of most (>95%) of the migrating fish in a way that is safe, timely, effective, and specifically exceeds a pre-determined management target. Determining the <u>efficiency</u> of a pass is more intensive and expensive than simply determining the <u>effectiveness</u> of a fish pass, and such assessments are therefore more common at strategically and eco-

logically important sites.

As noted above, a count of the fish passing through a fish pass (effectiveness) is not a measure of efficiency. With care, and some of the methods described in Table 9.1 estimates of numbers of fish passing can be used to get the needed measure of efficiency.

Overall the best method for monitoring upstream migration is telemetry because of the amount and quality of data it yields per individual fish. If a sufficient number of individuals are tagged and tracked then population-level evidence can be collected.

Table 9.1 Monitoring techniques for upstream migration

System	Comments	
Fish counters	Systems such as the Icelandic Vaki system (note that use of these systems is	
	limited at high turbidity and has a very low range of 40 cm or so) or resistivity	
	counters fitted to a crump weir-type exit from a pass (may not be suitable for	
	some species).	
Advanced sonar	Good system for observing detailed fish behaviour at short range (e.g. ARIS).	
	Relatively expensive and very sensitive to entrained gases.	
Camera	Useful system for observing fish passage but only in relatively clear water.	
	Can be combined with sensors that trigger cameras for short movies as fish	
	pass. Recognition of species is possible but can be difficult under turbid	
	conditions.	
Acoustic tags	Because of the greater detection range and their performance in deep and	
	saline water the use of these systems is preferred over PIT tags for more	
	detailed behavioural assessments, although the tags are more expensive.	
	Sensitivity is constrained in turbulent and aerated water.	
PIT tags	The use of PIT tags can be quite cheap, but detection range is limited to the	
	antenna range (which may provide the management evidence required). Ofter	
	used in shallow shallow water (typically about 1 m) or locations where fish	
	need to pass through confined spaces like fish passes.	
Radio tags	Provide very good information on individual fish behaviour, such as responses	
	to flow and approaches to a fish pass, but with less precision of location than	
	acoustic or PIT tags. Can be applied in in turbulent water, but poor detection	
	range in deep waters. Has a higher precision with manual tracking. Radio	
	telemetry does not work in saline environments. Very user-friendly.	
Fyke nets/fish trap (in	Catches fish as they enter a barrier, move through a pass or emerge as they	
combination with fish tagging)	pass a barrier. When combined with marking fish on the downstream side of	
	the fish pass, the efficiency of upstream passage may also be estimated.	

While this is a relatively expensive investment up front, tagged fish can be tracked for many months, or even years. This can yield information on the performance of more than one migration in a river, the identity and nature of other potential obstructions, preferred routes in different flow conditions, and the spawning destinations. Such data can be of considerable strategic value especially when working at a full basin scale with other potential fish passes, removals, and even road stream crossing upgrades.

Hydraulic measurements

The results of hydraulic measurements should be used to contribute to an overall fish pass evaluation programme. This should ideally include information on local hydrological conditions, the hydraulic conditions within the pass as well as the identity, numbers, sizes and swim capacity of each target species of fish that should successfully use 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 all of the target fishes. It also ensures that the facility operates effectively across the expected range of river discharge levels and can help to optimise fish pass operation. Results from hydraulic measurements should be required in the contractual approval process after a fish pass is constructed and commissioned.

9.3.2 Monitoring of downstream fish migration

There is generally a good understanding of the requirement of most temperate diadromous and many resident species to migrate *upstream*, however design considerations do not commonly recognise that most fish must also migrate freely downstream (Nyqvist, *et al.*, 2107, Calles & Greenberg, 2009).

It should never be presumed that downstream migration will occur in a safe, timely and effective way without thoughtful planning, modelling, implementation and monitoring. Several studies have increasingly demonstrated that this is complex, and that more work is needed to get a better understanding on this topic (Aarestrup & Koed, 2003; O'Connor, *et al.*, 2006; Baumgartner, *et al.*, 2013; Gauld, *et al.*, 2013).

Many impounding structures are now known to delay or even prevent downstream migration. This is because behavioural aspects deter many fish from approaching the structure. This can cause exhaustion as fish attempt to avoid the structure at a time (during downstream migration often with high flows) when they usually are minimizing energetic outputs. A much better understanding of fish behaviour, and how downstream migration facilities, such as notches or bypasses, should be incorporated into designs. This could be incorporated as an ongoing requirement that deserves better attention in design, permitting, dam and passage structure operation, monitoring, adaptation and enforcement.

Most monitoring of the performance of downstream migration facilities has focussed on estimation of mortality and damage to fish migrating downstream. This can be caused by entrainment of fish into water intakes or amputation by spinning turbines, to inform the efficiency of fish protection and guidance systems. Water intakes for consumptive use can cause mortalities in other ways since water is not returned to the river.

Water intakes for power generation can also cause mortality or damage. In these facilities entrained fish are exposed to spinning turbines and dramatic pressure changes in the penstocks and turbine chambers. 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 bywash.

The first step in analysing water extraction systems is to determine whether a facility to protect downstream migration of fish 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 other than slight adaptations to the water intake or turbine design or operation in order to improve conditions for safe migration. Ideally all possible migration routes e.g. turbine, spillway, sluices and any fish pass would be monitored at the same time to determine *overall* route choice and preferences and effectiveness, however this is often impractical. The evaluation should consider:

- What is the entrainment potential and rate at the water intake or through the turbines?
- What is the rate of damage or mortality to fish caused by turbines or other parts of the plant?
- What are the preferred safe migration routes for fishes to the facility and can they be improved to decrease delay and increase the number of fish finding it?
- What is the efficiency through the downstream migration facility, based on the attractiveness of the inlet to fish, and safe passage through the facility?
- What amendments to the structure's operating regime might be required to afford adequate protection to fish?

Purple labeo (Labeo congoro) fitted with an external Radio tag, South Africa



EXAMPLE

Trap and transport of silver eels (*Anguilla anguilla*) as a hydropower mitigation measure in Irish rivers

Author: Organisation:

Country:

T. K. McCarthy Ryan Institute, National University of Ireland Galway Ireland



The main conservation measures in Ireland's eel management plan (EMP) are: (1) Closure of all eel fisheries, (2) Improved upstream juvenile eel passage, (3) Mitigation of effects of hydropower dams, (4) Research and

FIGURE 1

Map of Ireland with River Erne, River Shannon and River Lee catchments indicated.



monitoring. Several large Irish rivers are affected by hydropower and silver eel trap and transport (T&T) was developed, as a short to medium term measure, on three regulated rivers (Shannon, Erne and Lee)

Silver eels are trapped (Figure 1) at fishing weirs in the lower R. Shannon (186m³s⁻¹ mean annual discharge) and lower R. Erne (92m3s-1 mean annual discharge) and with winged river nets at up-river sites (McCarthy et al., 2013, MacNamara and McCarthy, 2014). Annual T&T targets (e.g. Shannon: 30% and Erne 50% of silver eel production and Lee 500 kg) are set. Commercial fishermen, paid by the Electricity Supply Board (ESB), catch eels which are transported by ESB in special trucks or trailers to release points below the hydropower dams. All T&T operations are independently monitored. Catch data, fish passage telemetry and results of mark/recapture experiments are used for estimation of silver eel production and spawner biomass escapement.

T&T was initiated in 2000 on a pilot scale, and greatly extended in 2009 (Figure 2). In 2000-2016 Shannon T&T totaled 223.13 t. The Erne and Lee have totaled 26863 t and 3.39 t respectively since 2009. Thus over 500t of silver eels have by now been transported downstream of

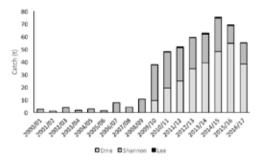
hydropower dams. Results of Shannon and Erne silver eel T&T are summarized (Table 1) for recent years, together with estimates of production and escapement.

Escapement has increased significantly since closure of eel fisheries in 2008. T&T also contributed significantly to spawner escapement, however, benefits of T&T were less than was suggested by the large biomass of eels transported. This is because Shannon turbine passage mortalities were frequently reduced by spillage to the safe old river channel (ORC) during high discharge conditions. As shown (Table 1) the real benefit of Shannon T&T was estimated at 16.59 t (i.e. 6.6% of the 251.23 t production). Shannon production and escapement values were not estimated in 2015/16 due to extreme flood events.

Major powerhouse retrofitting and increased spillage also reduced turbine mortalities during these years in the River Erne. The Erne data

FIGURE 2

Quantities (t) of eels transported downstream of hydropower dams in Ireland.



(Table 1) indicated that T&T benefit was 88.32 t (i.e. 25% of the 354.40 t production). Though fishermen benefit and valuable research data is obtained, our analysis suggests that alternative long-term silver eel conservation measures should also be evaluated.

EEL FISHING

Silver eel fishing at Roscor Bridge on the River Erne, Ireland. © Kieran McCarthy.



>>EXAMPLE

TABLE 1

A summary of the results obtained from monitoring (2012/13 to 2016/17) silver eel production (P), escapement (E) and the benefits of T & T on the rivers Shannon (one hydrodam) and Erne (two hydrodams). ORC = percentage using old river channel safe bypass route; mort % = turbine passage mortality.

Shannon				
Production (t)	Total T&T (t)	T&T as % of P	ORC (%)	
67.93	24.42	35.95	1.6	
79.97	22.56	28.21	24.27	
70.73	26.44	37.38	15.63	
32.60	16.71	51.26	8.51	
251.23	90.13	*38.20	*12.50	
	67.93 79.97 70.73 32.60	67.93 24.42 79.97 22.56 70.73 26.44 32.60 16.71	67.9324.4235.9579.9722.5628.2170.7326.4437.3832.6016.7151.26	67.9324.4235.951.679.9722.5628.2124.2770.7326.4437.3815.6332.6016.7151.268.51

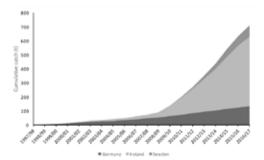
Erne

	Production (t)	Total T&T (t)	T&T as % of P	Mort 1 (%)	
2012/13	67.67	34.66	51.22	25.0	
2013/14	73.33	39.32	53.62	8.9	
2014/15	72.49	48.13	66.39	12.0	
2015/16	78.03	54.71	70.11	8.9	
2016/17	62.87	38.26	60.86	26.7	
Total/mean*	354.39	215.08	*60.44	*16.7	

In Europe T&T is undertaken in several countries but some are just pilot scale projects (e.g. Spain and France). The earliest European example

FIGURE 3

Cumulative T&T quantities (t) for the three main European countries using this conservation measure.



(1997 to date) involves the River Moselle, an international tributary of the R. Rhine. In Sweden smaller T&T was more recently initiated. The cumulative T&T amounts involved in the three main European countries (Ireland 69.7%, Germany 18.9%, Sweden 11.5%) are plotted (Figure 3) to highlight the scale of the Irish T&T activity, which involves almost 60% of the global T&T total and more that 65% of the EU total.

Eel T&T is also used as a hydropower mitigation measure in New Zealand and on the St. Lawrence River in North America. However, European hydropower power companies generally prefer mitigation by stocking with imported juvenile eels. Since 2011 pilot projects have started at other migration barriers e.g. pumping stations in the Netherlands. Silver eel catch and release also features in management of some commercial eel fisheries in France.

Mort (%)	Mort (t)	Escapement (t)	T&T as % of E	T&T benefit (t)
21.15	9.10	58.84	41.51	5.04
21.15	9.20	70.78	31.88	3.61
21.15	7.94	62.98	41.98	4.68
21.15	3.06	29.48	56.69	3.25
*21.5	29.30	222.08	*43.02	16.58

Mort 2 (%)	Total Mort (t)	Escapement (t)	T&T as % of E	T&T benefit (t)
8.0	10.21	57.37	60.42	19.00
18.9	8.81	64.29	61.16	13.35
13.8	5.86	66.53	72.34	14.56
20.1	6.33	71.65	76.35	16.97
27.3	11.49	51.38	74.48	24.44
*17.62	42.70	311.22	*68.95	88.32

EEL TRANSPORT TRUCK USED IN SILVER EEL T &T IN IRELAND © *Kieran McCarthy.*



EXAMPLE

Conte Anadromous Fish Research Center

Authors:

Organisation:

Country: U

Theodore Castro-Santos, Alex Haro, Benjamin Letcher & Stephen McCormick USGS-Leetown Science Center, S.O. Conte Anadromous Fish Research Center United States of America

The S.O Conte Anadromous Fish Research Center ('Conte Lab') was commissioned by the U.S. Fish and Wildlife Service in 1990. The Conte Lab is situated on the Connecticut River (Rkm 198), and was modeled after a similar facility that was built on the Columbia River during the 1950's. The mission of these laboratories was to improve effectiveness of fishways for native species by working with live, actively migrating fish. To this end, the Conte lab has 5 large flume structures, from 25-35 m long and the largest being 6 m deep by 6 m wide and capable of passing flows of up to 10 m³s⁻¹. These flows are possible because the facility is situated adjacent to a hydroelectric power canal. This provides access to the needed flow, which is discharged to the river downstream of the dam.

S.O. CONTE ANADROMOUS FISH RESEARCH CENTER

An aerial view of the S.O. Conte Anadromous Fish Research Center circa 1990. Since this time additional laboratory and flume facilities have been added to the complex.



FISHWAY EXPERIMENTS

Photographs of fishway experiments performed in the large flume facility at the Conte Lab. Fishways are tested with live, actively migrating fish. Movement is typically monitored using PIT, radio, or acoustic telemetry, depending on the study. The ability to modify designs quickly and test them with a range of discharge conditions allows for direct testing of designs to optimize passage.





Using these facilities researchers are able to test full scale prototypes of new fishway and guidance designs and technologies for both upstream and downstream migrating fish. They are also able to perform studies on basic behaviors that govern passage success, such as swimming performance, attraction or rejection to flow fields, responses to turbulence, etc. A series of holding pools hydraulically connected to the laboratory allows fish to be introduced into each of these flumes and subjected to tests without actually handling them. This is an important feature, because handling can cause fish to lose migratory motivation, compromising results of experiments.

The Conte Lab also has two 5,000 square foot wet labs with an array of tank sizes with photoperiod and temperature controls. There is also state-of-the-art equipment and expertise for physiological studies including large animal respirometry, fluorescent microscopy, hormone and receptors assays, ion transport, biochemistry and gene expression. Researchers also conduct field work in rivers and streams. The focus in streams is on culvert and both small and large dam effects on fish movements and population persistence.

The Conte Lab is staffed by an integrated team of ecologists, engineers, and physiologists who work both together and independently to advance conservation of diadromous fishes, with an emphasis on improving connectivity and passage. During it's near 30-year tenure, the Conte Lab has made many noteworthy contributions, including the introduction of PIT telemetry as a tool for evaluating fishway performance (Castro-Santos et al., 1996); development of removable surface weirs that improve passage of downstream migrants by reducing rates of flow acceleration into bypasses (Haro et al., 1998); development of new technical and statistical tools for quantifying passage performance (Castro-Santos and Haro, 2003; Castro-Santos and Perry, 2012); fundamental changes to our understanding of how capacity and behavior interact to determine passage success (Castro-Santos, 2005; Castro-Santos et al., 2013); negative impacts of delays in migration on physiological prepared-

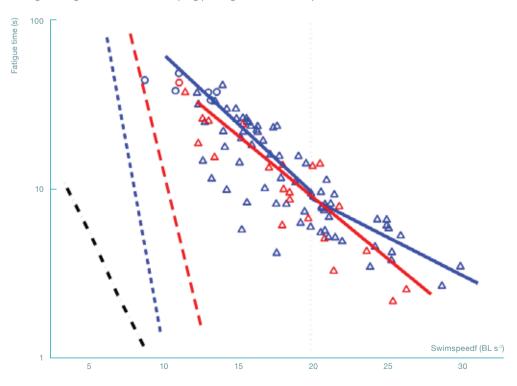
>>EXAMPLE

ness for seawater entry of downstream migrating juveniles (McCormick *et al.*, 1999; Zydlewski *et al.*,); and evaluation of the effects of habitat fragmentation and environmental change on population dynamics (Letcher *et al.*, 2007, 2015; Bassar *et al.*, 2016).

Much of the success of the Conte Lab can be attributed to its scale and the availability of large amounts of flow to run experiments. There are limitations however: because water is discharged to the Connecticut River only species native to the Connecticut River can be tested in the large flumes. Although this includes many of the species native to the East Coast of North America, important questions remain about how well lessons learned for these species will translate to other species around the world. One solution to this is for researchers to focus on fundamental aspects of behavior, performance, physiology, and ecology in order to maximize global relevance. Ultimately, however, more such facilities must be built in other locations if we hope to extend the success of this model to other regions.

FIGURE 1

Relationship between swim speed and fatigue time of brook trout (blue lines), brown trout (red lines), and rainbow trout. Solid lines and points show data collected at the Conte Lab, which are compared with previous studies performed in laboratory swim chambers. Fish that are allowed to swim volitionally are able to achieve much greater endurance than previously believed, allowing for much more flexibility in engineering criteria when developing passage structures. Reprinted from Castro-Santos et al. 2013.



Fish research in the Hunze River

Regional Water Authority Hunze en Aa's is carrying out a long term fish migration study on the Hunze River in the northeastern part of the Netherlands. At this location in the lower reach of the river the upstream migrating fish are being caught with a fyke net construction. A selection of these fish will be fitted with PIT-tags to follow their journey upstream. © Peter Paul Schollema.



Monitoring effectiveness and efficiency

It is important to understand the mechanisms that can improve the rate of safe, timely and effective downstream migration through structures by all expected species. It is equally important to assess the performance of facilities, to inform us how to prevent or minimise damage and adapt structures and their operation.

The assessment techniques previously described for the monitoring of upstream migration, are generally applicable for downstream passage as well. Catching and tagging fish upstream and then recapturing them downstream of the extraction point or the bypass can provide information on downstream passage effectiveness, timing, behaviour, and allow researchers to check for any physical damage incurred by fish. This allows an estimate or index of the number of fish that descend a Nature-like fishway and bypass or pass an inlet screen.

The selection of a fish capture technique is site- and flow-dependent. Methods vary, from simple netting, trapping or electrofishing. Other capture techniques include various designs of traps including Canadian rotary screw traps and Wolf traps which are increasingly used to sample salmon smolts during their downstream migration. The best results for tracking fish and learning about their behaviour are obtained when using radio or acoustic tag telemetry, PIT tags or in some cases in larger rivers, hydro-acoustic 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 extractions.

Where there is more than one potential route for fish migration through a barrier it is important to know which is the preferred route during different flows so that the structures are managed appropriately to maintain or increase its effectiveness. To determine this, studies will need to focus on trapping within each route. This could 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.

This can be with dye marks or appropriatelysized plastic tags, and marked fish can be recaptured using fyke nets or some other nets or traps downstream of each outlet structure. With this system, the effectiveness of a bypass can be determined. If additional information about the efficiency is needed the use of telemetry is generally necessary.

The loss through entrainment into extraction conduits and the damage and mortality of fish at other facilities should be determined for each target species in terms of numbers and, if relevant, total 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 rate of mortality or damage should be calculated for each species so that 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 extraction, 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.

9.4 GENERAL CONCLUSIONS

All upstream and downstream fish passage facilities should be designed with clear objectives in mind for the safe, timely and effective passage of all species appropriate for the river. Once fish passage requirements for migration through or around obstacles have been clearly defined, then a monitoring programme should be designed. Important factors to consider in a monitoring programme include the impacts of measures, the scale of the response and the diversity of conditions in which to measure passage. It should also include costs, in terms of staff and equipment required, time schedules and the required period of monitoring so that key environmental flow conditions are included within and between years. Since monitoring will need to deliver information for each target species, it may only target a subset of months each year. In the case of Finland the upand downstream salmon migration usually starts in April-May in the southern areas, 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 for each relevant species.

It is important that the chosen method does not adversely affect the migrating fish whenever possible.

Monitoring programmes may be a requirement of the national organisation/agency charged with protecting fisheries, or barrier and fish pass owners may choose to take advantage of the opportunity to initiate strategic monitoring themselves. Monitoring is is often a condition of licensing for the structure that requires a fish passage. We believe that in most cases this should be a condition of licensing and continued operations. In many cases monitoring programmes can be done in collaboration with fisheries agencies and student projects. In the Penobscot River in Maine. USA a series of PhD and Masters students have helped document the impacts of dams and dam removal on salmon adults, smolts, American shad, and sea lamprey from 2007 through to printing of this book.

New projects to engineer fish passage retroactively onto old weirs and dams should also have appropriate monitoring built in to the development plan to demonstrate that fish migration has 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.

CHAPTER 10 COMMUNICATION

PR INCE TON MYDRO

WORLD FISHS

MIGRATION DAY

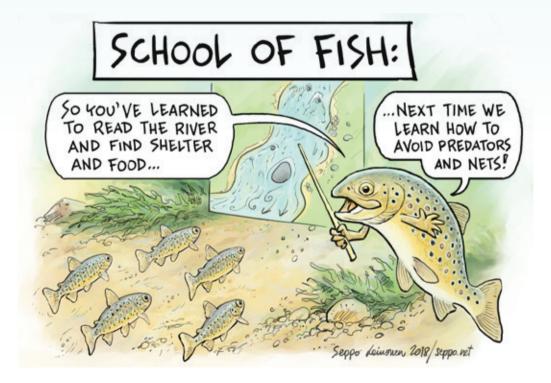
GELEBRATES

The celebration of World Fish Migration day on the Connecticut River, boating event organised by Princeton Connecticut, USA, © Laura Wildman.

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INTRO

Throughout this book, we have highlighted the actions required to bring together various policies and plans to implement ground projects that protect and/or restore fish passage. One critical component which is often overlooked is the need to generate enthusiasm and emotional connection to rivers and establish and maintain the incentive to restore fish migration. By stimulating human connections with rivers and their migratory fish and promoting benefits, through communication, cooperation, and knowledge exchange, we can have a larger impact on both rivers and humanity. To achieve our goals to transform policies, in order to protect and reconnect river basins on a global scale, it is recommended that practitioners prioritise communication efforts. Working together, we can optimise knowledge exchange and by creating awareness we can influence policy at local, national and international levels.



10.1 OVERCOMING CHALLENGES THROUGH COMMUNICATION

The challenge to manage river connectivity and restore functional fish migrations is rarely easy, but nearly always possible. The key to the successful implementation of strategies and ultimately the protection and restoration of fish migration can be found in the inclusion of open and consistent communication within each step in the Swimway approach (Chapter 1). This includes incorporating communication and instilling enthusiasm within the development of a good vision, securing funding, knowledge development, stakeholder involvement and the implementation of restoration measures and development of supportive policies. Indeed, there are many examples of successful projects where communication has played an integral role within each of these processes. A good illustration of this is the Fish Migration Plan "From Sea to Source" of Regional Water Authority Hunze en Aa's in the Netherlands, which resulted in the opening of more than 300 km of rivers and canals.

Stronger partnerships of collaboration towards a common goal has proven successful in research and conservation efforts primarily because they include more diverse viewpoints and facilitates broader collaboration and mutual support. In the Penobscot River, Maine, USA, the success of restoring access to thousands of kilometres of flowing river is attributable for the most part to the Penobscot Indian Nation bringing in multiple stakeholders. NGO's, tribal, state and federal stakeholders along with the industrial dam owner were all involved from the beginning of the project and continued to foster good communication throughout.

Even though there are great projects that have benefited from creative communication strategies, there is still much to be learned about overcoming challenges at multiple levels. This is applicable for improving knowledge sharing, connecting between sectors, and working together in partnerships to improve the rate and quality of activity and to involve and activate more stakeholders. There are different challenges and issues, for which new approaches are needed. Below we focus on some of the key challenges to improve communication and thereby reach our goals.

10.2 IMPROVING COMMUNICATION BETWEEN SPECIALISTS AND PRACTITIONERS

To improve the quality of knowledge that has developed through past achievements and experiences, researchers (working on fundamental information development), river managers and practitioners (learning through experience and the application of lessons-learned), would benefit from coordinated knowledge exchanges, through the development and active use of collaborative networks. This has not always been easy. For instance, the exchange of reports, project records and scientific publications between researchers and practitioners has often not been as effective as it should be. Many reports by practitioners are written in local languages, may not be formally published and are difficult to disseminate. Research articles on the other hand may be overly technical or not readily available to others outside of research institutions and trade networks.

Amazing elvers

A young child intrigued by elvers during a World Fish Migration Day event that created awareness by means of education in the Penobscot River, Maine, USA. © Joshua Royte.



SPECIES EXAMPLE

The status of the anadromous sea lamprey (*Petromyzon marinus*) in the Atlantic

Authors: Organisation: Country:

Stephen M. Coghlan Jr. & Catherine Schmitt University of Maine USA



INTRODUCTION

Natural History

Sea Lamprey belong to an ancient group of fishes that include the oldest living vertebrates. They resemble eels, but lack jaws, paired fins, true bones, and gill covers. Diagnostic features include a suctorial (suction cup-like) disc mouth, seven external gill pores, and a cartilaginous skeleton. Mature adults leave the marine environment to ascend swift, rocky streams in the spring to spawn. They use their mouths and vigorous tailbeats to drag cobble-sized rocks into a pile and remove fine sediment, creating large pit-and-mound nests in riffles. Adults die shortly after spawning.

Fertilized eggs incubate in the nest. After hatching, larvae drift or swim downstream and burrow in fine sand or organic substrate amid calmer currents. After three to eight years of filter-feeding, larvae transform into juveniles and migrate to the sea. There they attach to host fish and use their horny teeth and rasping tongues to remove flesh and suck fluids. After about two years, feeding ceases and juveniles mature as they enter fresh water.

Sea lamprey are "ecosystem engineers". Adult's nest-building creates beneficial microhabitats for drift-feeding fish and insects. It dislodges sediment, algae, eggs, and insects for downstream foragers. Larvae feed on detritus, transforming energy, recycling nutrients, and burrowing which oxygenates sediments. Carcasses and eggs contribute marine-derived nutrients and energy to the surrounding ecosystems.

Geographic Distribution

Anadromous sea lamprey range from Florida to Greenland and from Finland to the Mediterranean in the North Atlantic. Landlocked populations exist in the North American Great Lakes; there is disagreement over whether sea lamprey were native to the Lake Ontario watershed; but populations in the Upper Great Lakes are considered invasive. Over \$16 M/year is allocated to control them.

DETAIL OF SECTORIAL DISC MOUTH © Stephen M. Coghlan Jr.



SPAWNING SEA LAMPREY © Stephen M. Coghlan Jr.



Human Impacts

Sea lamprey may travel thousands of kilometers and require a variety of interconnected habitats; threats therefore arise from habitat loss. Dams block access to spawning habitat, development activities destroy in-stream habitat, and pollution and eutrophication degrade water quality. In North America, sea lamprey are not currently valued as food, although they were harvested by indigenous peoples for centuries.

SOLUTIONS

In North America, with a few exceptions, almost no quantitative data exist on lamprey abundance to enable assessments of native population status. No explicit policies exist to protect anadromous sea lamprey, probably because the species is non-charismatic, attracts little commercial interest, and suffers from negative public perception associated with invasive landlocked populations. However, current efforts such as in the Penobscot River, Maine, designed to holistically rehabilitate the entire "suite" of native sea-run fishes and ecosystem processes, directly benefit anadromous sea lamprey. Dam removals have facilitated range expansion and population increases of sea lamprey in Maine streams. Dam removals coupled with a focus on ecosystem-level restoration are the best solutions for anadromous sea lamprey.

WHAT ARE THE KEY DRIVERS?

Key drivers are ecosystem-level changes resulting from industrialized economic growth, such as disruptions in river temperature and flow regimes from climate change, and changes in prey fish populations at sea.

LOOK TO THE FUTURE

Restoring aquatic connectivity and food web linkages will benefit sea lamprey. Economic and/or societal pressure to increase generation of hydroelectricity might slow or even reverse dam removal and habitat restoration initiatives. Public education on the value of sea lampreys as "ecosystem engineers" and "living fossil" components of the native fish community will increase appreciation. Research is needed on population abundance, secondary production, and links with prey fish populations in the ocean.

ICONIC SYMBOL: HAPPY FISH

Bruno Doedens (SleM, The Netherlands) & Kerry Brink (World Fish Migration Foundation, The Netherlands)

The Happy Fish is an icon launched during World Fish Migration Day 2016, which symbolises free migration for fish populations (Waddenvereniging, 2016). It is a symbol that everyone can use to signify that their work enables free passage for migraoty fish.

The ambition is that all organisations, people and projects around the world use the Happy Fish to unite together toward a common goal of thriving and healthy migratory fish populations. It is a way to show global commitment to protecting migratory fish, which with repetition can be used to get the attention of policy makers, governments and decision makers. We want to make fish happy, that is what we are all doing this for!

Happy Fish Symbol

Happy Fish Symbol to signify free migration for fish populations. Design Happy Fish. © Bruno Doedens / SLeM (registered brand) / Waddenvereniging.





World Fish Migration Day 2016

Launching Happy Fish during the World Fish Migration Day 2016 at the Afsluitdijk. © Waddenvereniging.



One solution is to work on making more of this information available on well-publicised websites in the English language, and finding outlets to translate information when it is the only way to serve local purposes.

There are many other tools that can help improve dissemination of information, sharing knowledge and networking. Below are number of effective and simple tools that can optimize communications between experts working in the field of fish migration.

10.2.1 Tools to exchange knowledge, connect people and facilitate networking Workshops focused on innovations

Workshops where experts, both local and international, come together to discuss issues and brainstorm new innovative ideas can be highly effective.

Workshops are great platforms to share different experiences and expertise that ultimately improve solutions for developing new and better fishways. These workshops are also a way for expert groups to develop long-term personal and institutional relationships for sharing information and potentially working together, developing grants, research, innovative solutions, basin-scale plans, project implementation, monitoring and ensuring lessons that are learned are disseminated.

The Fish Migration River project shows how work-shops can be instrumental in improving our work. International experts from around Europe attended a workshop to discuss the solutions required to open up the Afsluitdijk, the 32km dike separating the Wadden Sea and the lake IJsselmeer in north-western part of the Netherlands. That dike currently forms a major barrier to fish migration in and out of the Rhine.

With input from international experts with different backgrounds and expertise, a world class opening to the Wadden Sea was consequently developed. For more information see: www.fishmigrationriver.com

Golden mahseer

The golden mahseer (Tor putitora) lives in the Himalayas, ranging from Pakistan to Thailand, with the largest and most secure populations being in northern India, Nepal and Bhutan. Babai River, Ganges Basin, western Nepal. © Arun Rana.



This project now has massive support from the public, local and national governments, nature organisations, scientists, schools, commercial fishermen and recreational anglers. A long-term vision to maintain support and to continue to increase public attention includes development of a visitor attraction, a reason to travel to see the site. There will also be a knowledge hub for people to experience and discover the issues around fish passage and environmental issues on both sides of the dike. The Fish Migration River also incorporates a story telling component using the "happy fish" symbol, which has now become an international symbol for migratory fish (van Scheltinga, 2017).

In India, a collaborative workshop with NGO's, local organisations, fisheries professionals and anglers resulted in the development of a package of research and conservation priorities for mahseer (*Tor* spp.) and important recreational species of India (Bower, *et al.*, 2017). These results highlighted local context, opportunities for addressing knowledge gaps through collaboration and the need for regional governance strategies and approaches to research and conservation.

Panels

Independent national panels of experts on fish migration matters have been developed in many countries and they have provided effective channels for guidance and the exchange of information and expertise. These panels act as centres for expertise on all issues relating to fish migration and passage facilities, for example the National Fish Passage Panel in England and Wales. Such panels provide advice on design criteria, the creation of standards and innovations in technology, policy, and strategy, on the implementation of locally and regionally appropriate regulations, and perhaps most importantly they provide advice and assistance to managers and local water management bodies. In some countries advice underpins legal approval for the form and function of fish passages. Some panels might also be able to advise 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 local or national databases.

Network groups

Expert network groups are usually comprised of local and regional experts that come together regularly to network and to share their work experiences with the group. These group meetings are great opportunities to share knowledge, to stimulate collaboration and project development through the formation of strong and often lasting partnerships. In the Netherlands, regional scale network called the Vissennetwerk is hosted by Sportvisserij Nederland. This is a platform for specialists to exchange information, knowledge and ideas around the themes of fish, fisheries and the environment. The group consists of over 350 specialists in the Netherlands and Belgium, who meet once every quarter to network.

There are many local networking groups around the world. In South Africa, the Swimway Programme, has recently created a group of 100 practitioners to improve networking opportunities. While in Germany, there are yearly workshops or forums on the topic of fish protection and downstream migration of fish (Ecologic Institute, 2016).

The relatively new concept of "Fish Markets" provides another networking opportunity. Groups of practitioners meet in different European countries and share practical experiences on the theme of migratory fish. Over the past few years these events have been held in Finland, the Netherlands and Sweden.

There are also international workshops on specific topics such as dam removal in Europe hosted by Dam Removal Europe (Dam Removal Europe, 2016) and CEMIG in Brazil (CEMIG, 2017).

In Europe, 23 countries participate in "Fitfish" workshops to promote and share research on the swimming physiology of fish as well as the implications for migration and aquaculture (www.fitfish.eu). Other cases where international communication between expert groups have been developed, include: the International Association for Danube research (www.iad.gs), North Atlantic Salmon Conservation Organisation (www.nasco.int), North Pacific Anadromous Fish Commission (www.npafc.org) and the information and knowledge management programme of the Mekong River Basin Committee (www.mrcmekong.org).

Conferences & symposia

International conferences and symposia provide valuable opportunities to exchange information on topics such as the restoration of river basins and more specific technical issues such as the design and construction of passage facilities. Recent relevant international symposia include:

- Fish Passage Conference: https://fishpassage. umass.edu. An annual conference on river connectivity and fish passage that has taken place at a variety of location in the US and around the world since 2011.;
- International Conference on Ecohydraulics: www.ise2016.org;
- Flatfish symposia: www.flatfish symposium.com;

- IFM (Institute of Fisheries management in the UK) annual conference: www.ifm.org.uk;
- International Conference on Watershed and River Basin Management: www.rbm2017.com;
- SIBIC VII Congress of the Iberian Society for Ichthyology: www.sibic.org;
- International Conference on Aquatic Sciences and Fisheries: www.waset.org.

Information on similar conferences can be obtained through the LinkedIn network. In addition to this, species-specific symposia such as the International Symposium on Sturgeons, are held to bring together scientists working on sturgeon and paddlefish around the world. It also connects members of affiliated sturgeon societies such as the Society to Save the Sturgeon and the North American

Exchanging knowledge and networking

A) Presentation during the Fish Market (Kalamarkkinat), event in Helsinki, Finland. © Herman Wanningen. B) Vendor presenting products used for hydro acoustic telemetry research, Kalamarkkinat, Finland. © Herman Wanningen. C) Demonstration of research techniques during a meeting of the Dutch/Belgian Fish Network (Vissennetwerk). © Connie Kolfschoten/Sportvisserij Nederland.







Sturgeon and Paddlefish Society (Rosenthal, *et al.*, 2014). These symposia are intended to update the state of knowledge, share experiences, identify research needs and cooperation's for conservation and sustainable management.

Across the globe there are many of these conferences and symposia. One of the key ambitions of the World Fish Migration Foundation is to connect these international symposia so that more benefit may arise. The goal is to stimulate international knowledge exchange and to connect people around the world. The Fish Passage conference, for instance, became international after a collaboration between American and Dutch colleagues. For many years, the Fish Passage conference was only held in the USA. Following an international alliance, the conference was then held for the first time in Europe in 2015, and in Australia in 2018.

In an attempt to further connect these events, a fisheries-related conference list is now prepared and distributed by a partnership of the World Fish Migration Foundation, the IFM, the European Inland Fisheries and Aquaculture Advisory Commission (EIFAAC) and the IUCN Freshwater Fish Specialist Group (FFSG). These communication portals provide a list of upcoming conferences scheduled for the coming years (www.worldfishmigrationfoundation.com) and is regularly distributed within a growing network.

Courses & webinars

On a global level, there seems to be a surprising lack of specific studies and courses focused on the development of fish passage expertise. The University of Massachusetts is one of the only universities that has a degree focussing on fish passage and resulting in students graduating as "fish passage experts". Other universities do have topics related to this, but are often not the focus.

There is a clear need to develop more such courses with a wider potential uptake for the growing ranks of practitioners around the globe. Such courses are an effective way to share knowledge with fellow specialists and practitioners. Practical courses are often linked with technical conferences, where in the days before or after the conference experts share their knowledge with others about technical topics such as dam removal, fishway design, management of fish passage along with various other topics. One concept is to develop a "Fish Passage Academy". This has recently been proposed by the World Fish Migration Foundation (Herman Wanningen, 2017, pers. comms.). This Academy is intended to create a single central location for courses on fish migration.

Webinars are an increasingly popular and practical mechanism to share technical information with others. They can reach a wider audience, for low cost, and be recorded for long-term usage. Many webinars on fish passage science are hosted by organisations, governmental departments, institutions and consultants and are often freely available to watch after the webinar date.

The Joint Committee on Fisheries Engineering and Science in the USA regularly hosts webinars on fish passage. This committee was established in 2011 by members of the American Fisheries Society Bioengineering Section (AFS-BES) and the American Society of Civil Engineers Environmental and Water Resources Institute (ASCE-EWRI). These institutions wanted to foster communication between the groups and provide opportunities for engineers and biologists to share relevant knowledge and learn from one another. The Atlantic Salmon Conservation Foundation (www.conservationdusaumon.ca) also hosts regular webinars that are open to the public in English and French.

Best practice guidelines & reporting

The challenge of designing passage solutions can be offset by reference to published examples of best practice. However in most cases, project work is not published, no matter how effective and elegant the solutions might be. There is, therefore, a challenge to locate appropriate examples of best practice - this is a great shame as these are, where available, generally of great help.

GUIDELINES AND BEST PRACTICE FOR FISHWAY DESIGN

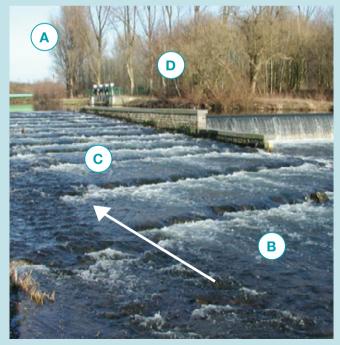
Marq Redeker (CDM Smith, Germany) & Wilco de Bruijne (OAK consultants, The Netherlands)

It is essential that best available practices and guidelines regarding fishway design are shared among people designing fish migration solutions worldwide. In Europe the German standard DWA-M 509 (DWA, 2014) represents the state of the art in knowledge and technology for the correct design, construction and operation of fish passes and fish-passable structures (e.g. culverts and flood retention basins). The recommendations in DWA-M 509 represent best practice for faultless technical behaviour of fish passes. The standard is available in German and Turkish languages; an English translation is in progress.

Likewise, the three main factors that determine the efficiency of fish passes (i.e. attraction, passage and operation time) also apply to fishways that ensure safe downstream migration at fish migration obstacles, e.g. fish screens with bypass channels for water intakes or hydropower plants. The guidelines DWA (2005), EA (2005) and EA (2011) offer comprehensive overviews of fish protection technologies and downstream fishways.

Guidelines

Main factors for fishway efficiency according the the German DWA guideline for upstream fishways. When one designs a fishway, several aspects should be taken in to account to optimize the efficiency. These are: project and site specific conditions, attraction efficiency, passage efficiency once a fish has entered and finally the operation time throughout the year. © Marq Redeker.



- A Project and site specific conditions
- B Attraction efficiency
 - Large-scale location
 - Entrance position
 Attraction flow:volume/ flow impulseangleflow velocity
- Passage efficiency
 Migration corridor
 - Geometry:water depthchannel/ pool
 - size slots • Hydraulics:flow
 - velocityturbulence
- D Operation time
 ≥ 300 d/a

HOW COALITIONS CAN MOVE PROJECTS FORWARD

Kerry Brink & Peter Gough (World Fish Migration Foundation)

Ruim baan voor vis

In the Netherlands, the project "Ruim Baan Voor Vis" was initiated by a partnership of four Water Authorities that wanted to work together toward a common goal; opening rivers for migratory fish. The cooperation of 4 regional water authorities, supported with €6 million from the Wadden Fund, led to tackling all barriers along the coastline of the North of the Netherlands. To demonstrate the outcomes of this work, they have developed a fish migration map that shows the status of restoration projects at barriers within the respective regions (Ruim Baan Voor Vissen, 2017).

Rivers Trust

In England, the Rivers Trust movement is an umbrella body that supports 40 member trusts across the country that are working to protect, promote and enhance freshwater ecosystems for people and nature. In 2016, the cooperation of 30 trusts resulted in the opening of 389 km of river to fish passage, eased, passed or removed over 88 fish barriers, and improved 542 km of river habitat: www.theriverstrust.org. In Wales, Natural Resources Wales (NRW) works with Afonydd Cymru (the parent body for rivers trusts in Wales). In 2015 NRW reported that they had completed 62 fish passage projects opening up more than 700 km of river habitat for diadromous fish.

Haringvliet

For many years the Haringvliet estuary has been closed by sluice gates, which has blocked the route of migratory fish into the Rhine river catchments. Following pressure from coalitions of organisations within the Rhine and Meuse Rivers the opening of the dynamic estuary was approved in 2011 by the Dutch government. In 2015, WWF-Netherlands and five partner organisations were awarded a \in 13.5 million grant to restore the tidal landscape of the Haringvliet estuary, with a special focus on restoring European sturgeon, which are disappearing due to pollution, barriers blocking the migration routes and overfishing (WWF, 2017).

Ecological measures in the Haringvliet estuary

Visualization of the ecological measures in the Haringvliet estuary, used to show the huge potential and impact of the measures and inspire people to get involved. © Bureau Stroming B.V. commissioned by WWF.



In Chapter 8, some of the more well-known existing manuals are listed (Section 8.2), which are partly used to describe the three-step fish pass design and construction approach.

Using social media

Social media provides numerous ways to stimulate knowledge exchange:

- 1 WhatsApp groups are now being formed to both share information and stimulate relationships in an often fun, informal manner. This includes Fish Migration News in the Netherlands and World Fish Migration Day WhatsApp groups as well as a Glass Eel Volunteer WhatsApp group. These are usually set up in response to specific projects or regional network groups.
- 2 Starting in 2009 fish migration experts from all over the world began to exchange information and ideas and to discuss matters of mutual interest on LinkedIn (www.linkedin.com) through several networks:
 - a River Connectivity Network;
 - b Fish Ecology Network;
 - c Dam Removal and Fish Passage Network.

These networks have grown quickly since inception and are an increasingly valuable asset.

- 3 Social media has thousands of organisations who share their projects and news on a daily basis including Facebook, Twitter, Instagram, Youtube along with others. This is a powerful tool for people to connect with active organisations and to keep up with international information around the theme of fish migration. It is also an extremely useful tool to create enthusiasm and invoke action. One key to linking practitioners is the use of handles (@) and hashtags (#) as key words to link common interests or organisations. The @fishmigration twitter account has currently about 3,000 followers.
- 4 Websites are an important medium for sharing

information. This is not only restricted to organisation sites and project information, but also through interactive information systems, such as GIS mapping databases, Webmaps, and dataviewers that offer information relating to ecoregions (Abell, *et al.*, 2008), rivers (Lehner & Grill, 2013), barriers (Lehner, *et al.*, 2011) and fish distributions (IUCN, 2017).

Around the world there are thousands of websites with information and databases. Currently there are just a few well-known websites that consolidate information from all of the websites (databasin.org/maps).

Many results and outcomes of local fish passage work and projects are not available on any website to be shared. This is yet another reason why meetings, conferences, workshops and panels (Section 10.2.1) are essential.

It also speaks to the need for more scientists and practitioners to:

- · Become more fluent in social media messaging;
- Prioritize publishing;
- Improve skills to translate their science and engineering and policy into language that is accessible to adults and in many cases children accessing the internet around the world.

10.3 IMPROVING COLLABORATIONS AND COMMITMENT

There is a widespread and increasing focus today on the promotion of partnerships, working to deliver environmental improvements and sustainable solutions for all stakeholders. Close cooperation between government agencies, water authorities, private and public sector entities is essential. Particularly if mutual interests and opportunities are to be identified, holistic solutions developed, and resources shared to address environmental needs. This represents a relatively recent cultural shift and is clearly demonstrated in groups that include fishermen, private fishery owners, tribal communities and those interested in wildlife and biodiversity. The groups commonly have strong views about the

SPECIES EXAMPLE

Tigerfish (*Hydrocynus vittatus***)** of the Sabie River

Authors:

Addresses:

Country:

Gordon C. O'Brien¹, Matthew Burnett¹ & Robin Petersen² ¹University of KwaZulu-Natal & ²South African National Parks South Africa

TIGER FISH © Herman Wanningen.



The Sabie River is an iconic ecosystem in the Kruger National Park (KNP), a globally recognised conservation area in southern Africa. In the early 20th century, pollution from gold mining activities upstream of the KNP on the Sabie River completely disrupted the wellbeing of the fish communities. The extent of the impact was described by stakeholders as a "riverine waste land, devoid of life" (Pienaar, 1979). Incredibly, after the closure of the gold mine in the 1960s, the ecosystem recovered and by the 1970's fish communities in the river had recovered to near historic conditions! The Sabie River has become the flagship of aquatic biodiversity conservation for the KNP and the region (Rogers and Biggs, 1999).

From the 1970's the condition of all other major rivers in the KNP deteriorated (Rogers and Biggs, 1999). Pollution and large dams built on these rivers, upstream and downstream of the KNP, threatened many socio-ecologically important fishes. This includes the tigerfish in the Sabie River which is now restricted from lowland river migrations by the Corumana Dam, positioned just downstream of the KNP.

The African tigerfish *Hydrocynus vittatus*, is a large growing, highly mobile, migratory, predatory fish of the Sabie River (Skelton, 2001). These opportunistic predators have been known to migrate extensive distances over short periods of time, more than 100 km within a few days (Økland *et al.*, 2005; O'Brien *et al.*, 2012). Although tigerfish in the Sabie River are isolated from the regional population downstream of the KNP, we hypothesise that the Corumana Dam provides winter refuge habitat for the local population. The long term suitability of the lake associated, with the dam, as a winter refuge for tigerfish is however unknown.

In spring and summer, with increasing water temperatures, marauding mobs of similar sized tigerfish initiate reach scale migrations from the dam into the Sabie River (Roux, 2015). They navigate past two partial (depending on flow volumes) barriers into the lower and middle reaches of the Sabie River where they improve in condition prior to summer spawning. Juvenile tigerfish recruit into the river and seek marginal, relatively shallow (≤ 0.5 m) habitats that have overhanging marginal or instream vegetation and substrates that provide juveniles with cover from predators (Skelton, 2001). Beyond the fingerling phase the tigerfish juveniles shoal and begin to occupy open water where they use their speed to prey on pelagic invertebrates and fishes. Historically juvenile tigerfish (y+1) are hypothesised to migrate into the lower reaches of the Sabie River and Inkomati River (Roux, 2015). Construction of the Corumana Dam presented a risk that juveniles would not have suitable habitats and be out competed by subadult and adult tigerfish and other predators. The dam may also affect habitat availability for other fishes that form an important part of the food web of the river and may ultimately affect the viability of tigerfish.

We need a better understanding of the importance of river connectivity in the Sabie River and the ecology of the charismatic tigerfish so that sustainability may be maintained. Conservation initiatives are being proposed to characterise the impact of developments associated with the Corumana Dam and other fish migration issues with local and international stakeholders.

FISH MIGRATION IN THE KRUGER NATIONAL PARK

A) Sabie River near Skukuza, KNP. © Peter Paul Schollema. B) Engelhardt Dam fish ladder in the Letaba River. © Robin Petersen. C) Telemetry studies in monitoring tigerfish behaviour in the Kuger National Park. © Gordon O'Brien.







needs to improve fish stocks and fish habitats, and have a gained strength as they are united in their efforts towards a shared vision and common objectives. The Penobscot River partnership, showed how tribal residents, companies and nature all benefited from the restoration of the river and migratory fish (www.penobscotriver.org).

Early and transparent engagement encourages the sharing of ideas and approaches and will lead to better strategies for delivering positive outcomes for a project. The Danube Management Plan, developed by the ICPDR, is an illustration of how a collaboration among NGO's. researchers and hydropower companies can result in positive measures and restoration of habitats. Active involvement of stakeholders and civil societies across 19 countries in the Danube River basin was part of an intensive communication strategy that ensured a high level of public consultation in the development of the required plans. This included activities such as stakeholder workshops, online surveys, public calls for comments on draft documents, social media and also linking up with global events such as World Fish Migration Day (ICPDR, 2015).

Before engaging partners, a clear understanding of local issues and priorities is required, together with clarity on potential areas for collaboration and areas of potential conflict. Know your partners, by listening carefully to them. It is important to set goals that are achievable and to agree on these before commencing a project. If different groups have differing objectives then it may not be realistic to proceed in a partnership without further exploration or agreement on differences and where there are common goals.

The nature and extent of commitment from each partner should be identified, recognising that different partners play different roles and can offer different levels and types of resources. For example, some may offer technical knowledge whereas others may offer practical experience, local information, manpower for fieldwork, help with permitting, outreach or even offering the design and engineering support that most fish pass solutions require. Collaborations work best when you can optimize the different skills and capabilities that each partner can bring to the group, which can be recognized and celebrated.

It is not possible to identify a general approach to partnerships as every situation is different due to local factors. Such as the range of available partners, the scale and nature of the challenges to be resolved, local policy, and costs and available resources differ significantly. Nevertheless, there are some key elements that are often helpful.

ESSENTIAL REQUIREMENTS FOR A SUCCESSFUL PARTNERSHIP ARE:

- Mutually agreed upon ambitions and 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 and consistent communication among partners;
- Clear definition of roles and responsibilities, with accountability, for each of the partners with a defined central supporting (backbone) partner that convenes the process, and potentially another that provides the backing needed to support the collaboration and forward progress.
- Improved awareness among all partners and stakeholders can also secure better outcomes by simplifyin negotiations. For instance, governmental officials who have been invited to visit a sturgeon visitors centre are more aware of the importance of their work on protecting these species.

10.4 CREATING AWARENESS AND ACTIVATING CITIZENS

Integrated water management relates not only to the surface waters and river banks, canals 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 diverse group. Regardless of background, all people should have a basic understanding of water management issues, and that specific measures to restore and protect fish migration should be

World Fish Migration Day Celebrations

A) Releasing sturgeon and eels, Acquario di Cattolica. © Cristiano da Rugna. B) Mongolia © TNC, Tuguldur E. C) Police marching with Addis Ababa University students and staff across the main streets of Bahir Dar City, by the shore of Lake Tana, Ethiopia. © Dr. Abebe Getahun, Addis Ababa University.





publicised to improve public understanding of the issues and appreciation of the resource.

Similarly, it is important that professionals involved in water and Swimway/river basin 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 the Water Framework Directive, drives fish passage and water management policy, strategies and implementation.

It is important to provide information to the public in a form a diversity of audiences can understand and which helps them to draw their own conclusions about priorities. If the general public and decision makers do not understand that the free migration of fish is usually prevented at dams and weirs, then it is unlikely that the issues arise as significant and problematic. An initial campaign may provide information just 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 for the full spectrum of recipients is vital to ensure a shared understanding of problems and future priorities and possibilities for action.

There are various activities and platforms which can be used to facilitate and enhance engagement with relevant audiences. This may include international awareness days such as World Fish Migration Day, visitor centres at fish passages, outreach programmes, educational activities or incorporation of an iconic symbol for fish migration such as the 'Happy Fish'.

10.4.1 World Fish Migration Day

World Fish Migration Day (WFMD) is a one day, international event that is held every other (even numbered) year to foster worldwide awareness of migratory fish and their need for free-flowing rivers (World Fish Migration Day, 2016). It is all inclusive and an opportunity for local organisations to collaborate with others to create awareness about migratory fish and to call attention to the threats and opportunities for protection and restoration. Local organisations from around the world can simply join WFMD and organise an event event on a specific day in April or May depending on the year.

This approach encourages organisations to create awareness and engage with citizens in their own way through a diversity of strategies to:

- Engage high level delegates in their regions.
 A notable event was held in Estonia, where politicians and researchers met to discuss and make commitments for the removal of the Sinidi Dam;
- Have an opportunity to connect with iconic figures such as television celebrities and ministers, who can attract public attention and start crucial conversations among a broader audience. Zeb Hogan, from National Geographic Wild, was a key ambassador who promoted WFMD during 2016 (WFMD, 2016);
- Showcase their projects and activities to people who can benefit from the new fish passage or including people looking at similar options in other rivers (Brink, 2016) (Table 10.1);
- Make reporting on the local project or efforts more attractive to the press when local projects are presented in a global context; and
- Use it as a strategic (high visibility) moment to launch products and tools. In 2016, the Swimway Poster was developed for launch on WFMD (www.swimway.org). It included information about migratory fish, the problems they face and the solutions that have been developed.

A vision for WFMD is that all people working on fish migration around the world would host an event on a single day to get the attention of governments and industry to ultimately safeguard free-flowing rivers and to restore Swimway routes of migratory fish.

The first WFMD was held in 2014 in over 50 countries at more than 270 events (Brink, 2014; World Fish Migration Day, 2016). In 2016, the events nearly doubled to 450 different locations

Table 10.1

The impact WFMD has had on global fish migration objectives, as set by the World Fish Migration Foundation in collaboration with key partners.

WFMD2014	First global celebration: Creating awareness in over 250 events;
	 Bringing thousands of organisations together;
	The USA based Fish Passage Conference was held in Europe for the first time
	in 2015;
	Kick started the WFMF;
	 Kick started close collaborations with international colleagues.
WFMD2016	Launch of the Happy Fish Symbol;
	 Development of a global Swimway project;
	 Development of a database with over 5,000 contacts;
	Creating awareness: over 70 million people;
	 Developed network of people to contribute to From Sea to Source Book;
	 Active support from leaders and public figures;
	Development of Swimway Poster.
WFMD2018	 Developing a global database of contacts across all continents;
	 Launching 2nd edition of From Sea to Source book;
	 Active support by numerous public figures and leaders;
	Development of good relationships with key international groups;
	 Translation of Swimway poster into several languages.

hosted by over 2,000 local organisers (Figure 10.1). This resulted in a global reach of approximately 70 million citizens through social media, traditional press, national news broadcasts as well as many other different channels.

The overall global impact of the WFMD is widely considered to be high, having both implications for local awareness, improving connections among practitioners, and producing tangible results in awareness, policy change, organisation, and action. World Fish Migration Foundation activities have had a global impact on fish migration through WFMD activities and collaboration with partners.

10.4.2 Visitor centres

Visitor centres situated close to fishways, dam removal sites, or other fish migration activities can provide citizens with opportunities to learn about the life-history of migratory fish and what fish passage looks like up close. Around the world there are many visitor centres, although most are in the USA, the UK and other European countries. The centres often provide exhibits and experiences that vary from a simple display area to an interactive exhibit hall that provides visitors with fun games, information and activities. In many cases there are viewing windows that tend to attract the largest number of visitors to see live fish moving within a fishway.

Advantages and opportunities of visitor centres:

- They educate citizens about why fish must migrate and why fishways are so important;
- They can activate citizens to become interested and potentially contribute to free-flowing rivers;
- They encourage community ownership, pride and involvement, which can also enhance tourism in the area;
- Centres can provide a platform for cooperative education programmes that foster cultural and ecological stewardship of river systems;

EXAMPLE

World Fish Migration Day

Author:

Organisation: Country: Joost van Deelen, Pao Fernández Garrido, Kerry Brink & Herman Wanningen World Fish Migration Foundation Netherlands

INTRODUCTION

Migratory fish such as catfish, sturgeon, eel and salmon support the diets, livelihoods and recreational opportunities of millions of people worldwide. However, these fish face a number of threats. Physical barriers, including dams, weirs and sluices, are probably the most widespread challenges for these species. Migratory species depend on open rivers and natural flows of water to reproduce, feed and complete their life cycles. The importance of migratory fish and their migration routes is largely unknown amongst the general public. As a result conservation efforts are still largely poorly developed and many migratory fish are severely threatened. To counter this lack of understanding a global World Fish Migration Day was started in 2014, to be celebrated every two years.

WHAT DID YOU DO?

The main goal of World Fish Migration Day is to improve the public's perceptions and understanding of the importance of migratory fish, the need for healthy rivers and the options we have to avoid impacts. World Fish Migration Day consists of many local events ranging from educational tours of river restoration projects to global inaugurations of "fishways" and dam removals. It also includes family and educational events such as celebrations at zoos and aquariums, and kayak tours. World Fish Migration Day is inclusive in its design and focused on bringing together scientists, governments, NGO's and the interested public. With the help of the organizers of local events on this global day we hope to create greater global awareness and subsequently achieve a big impact on fish migration policies, measures and management.

HOW DID IT WORK OUT?

Over 2,000 organisations from around the world celebrated the 2nd World Fish Migration Day on 21 May 2016. At 450 locations organisers hosted new, big and great local events to grow awareness about migratory fish and to identify the struggles and needs of these migratory fish.

The statistics of WFMD2016 tell a wonderful story (WFMD report, 2016):

- 450 Events;
- 82,000 visitors to events;
- · 63 countries;
- More than 15 million people reached on social media;
- · 2,000 organisations involved;
- 70 million people reached worldwide.

WFMD 2016 USA - PACIFIC LAMPREY RELEASE © Ralph Lampman.



It is quite probably the biggest fisheries event ever staged and the feedback and support has been tremendous from local communities to international leaders and icons:

Zeb Hogan, biologist at the University of Nevada and host of National Geographic Wild, Monster Fish: "We want people to realize what's at stake, understand what we've lost, and work together to protect and restore populations of these amazing and life sustaining fish"

Marco Lambertini, Director General of WWF International: "Fish migration is one of nature's wonders. It is more important than ever to conserve migratory fish on which ecosystems but also jobs and economies depend"

LESSONS LEARNED

World Fish Migration Day provides the great opportunity to combine efforts undertaken to help migratory fish and free-flowing rivers and thereby giving it a stronger voice.

Above all, World Fish Migration Day is inclusive. Everyone around the world is invited to join and/ or host an event no matter how big or small. It is something something for all those interested in migratory fish and free-flowing rivers, whether for their intrinsic value, as icons of a healthy environment or a vital natural resource to sustain people. We encourage all those with the same shared values to get involved in future World Fish Migration Days, for the sake of fish, rivers and people! More info: www.worldfishmigrationday.com.

EXAMPLE

River of Power - A novel 4th grade cooperative education partnership

Author: Organisation: Country: Robert Bauer Chelan County United States of America



INTRODUCTION

Located seven miles north of Wenatchee Washington on the Columbia River, the Rocky Reach Discovery Center is the place to learn "all things" Columbia River. The Discovery Center is the place to experience the Columbia up close. Guides are available to lead tours and answer questions.

WHAT DID WE DO?

Late in every school year, more than 1,400 4th grade students travel to the Discovery Center to attend the River of Power field experience at Rocky Reach Dam. Introduced as a small pilot education event in 2001, River of Power blossomed into a durable partnership between the Rocky Reach Dam Discovery Center, North Central Washington Education Service District and Wenatchee School District.

In the spring of each year, students participate in learning modules in-class prior to visiting Rocky Reach Dam. The modules educate the students on energy transfer, sources of electrical energy, dam construction, hydropower, the salmon lifecycle and the significance of protecting fish. Discovery Center Education Specialist, Bob Bauer helped write the curriculum and designed the hands-on activities for a portion of the science kit used with school districts in Chelan County. As the buses arrive at Rocky Reach for the field day experience, students are divided into several groups to travel through a series of stations where they touch, build, test and draw conclusions. Stations include building a dam, moving juvenile salmon downstream and adult salmon upstream past the dam and transferring kinetic energy from the river to electrical energy that turns on light bulbs.

Included in the in-class curriculum and field day experience is an emphasis on salmon in the Columbia River. As students build their own dams using a host of materials, they are challenged to

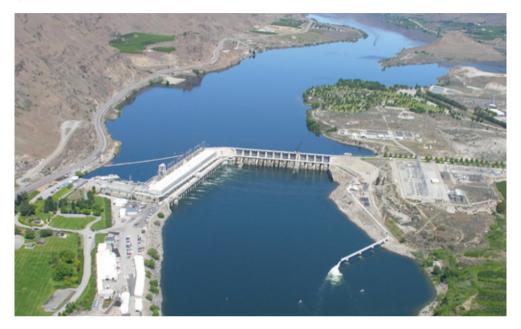
LOOK A SALMON IN THE EYE

Viewing windows for fish help to amaze and inspire children and adults.



ROCKY REACH DAM

Aerial view of the Rocky Reach dam in the Columbia River. This hydropower station is located 760 km upstream of the mouth of the river.



make accommodations for migrating fish. The challenge leads to them learning about fish bypass systems that help to keep juvenile salmon away from turbines and spillway gates. Later, they visit the Rocky Reach Dam 'one-of-a-kind' juvenile bypass system. This 1,400 m long, 2.75 m diameter pipe moves juvenile salmon safely past the dam.

Finally, students arrive at the most amazing station of all - the fish viewing room to peer through glass windows into the adult fish ladder. Here, 4th grade students can look a salmon in the eye, identify salmon species and differentiate hatchery salmon from wild salmon.

HOW DID IT WORK OUT?

River of Power consistently receives high praise from teachers, principals and community members - not only because more than 4,000 Fourth Graders participate in the in-class and one-day on-site learning experience, but also because it meets Washington State Learning Objectives - providing a benefit to teachers. River of Power has greatly increased awareness on the importance of protecting migrating fish that use the mighty Columbia River to generate power. It's made possible by bringing the Chelan County Public Utility District, the many school districts and the community together.

LESSONS LEARNED

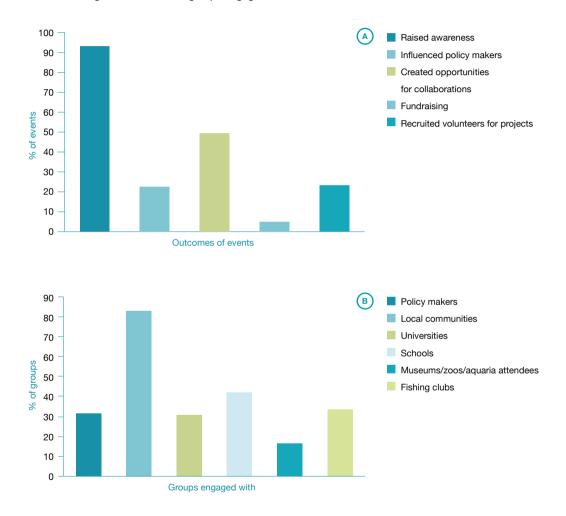
Look for every opportunity to enhance the learning experience. Each year is different and each year we collaborate with educators and community members to determine how the year can be even better.

For more information about the River of Power and other learning experiences:

www.chelanpud.org/learning-center/Education-Programs.

Figure 10.1

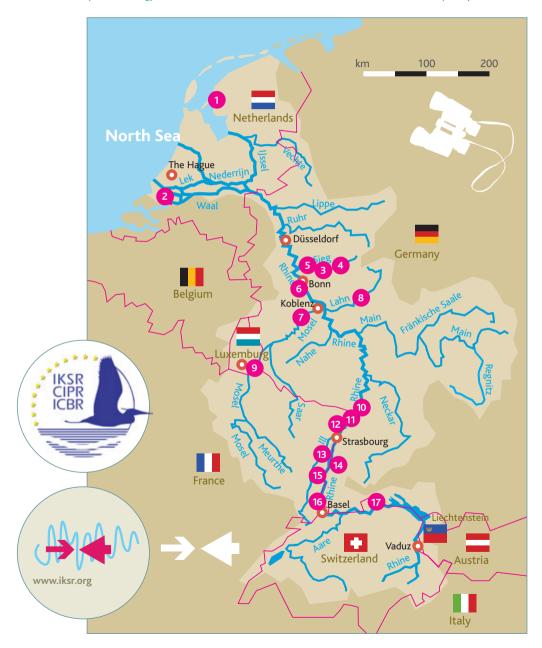
World Fish Migration Day 2016 events based on a survey of 140 participants who hosted events in 2016. A. Raising awareness, influencing policy makers, creating oppunities for collaborations were some of the key outcomes of WFMD events. B. Representation of the different groups that were engaged with or reached during WFMD. The main groups engaged with were local communities and schools.



 They are a way for governments, ministries and others working to open swimways to show the public what is being done. Millions of dollars are invested in measures to protect biodiversity and this is an important way to clearly demonstrate the outcomes of these large public and private investments. In the Rhine River catchment, the ICPR (International Commission for the Protection of the Rhine) demonstrates to citizens in the catchment the important lifeline this river serves for people and nature. In 2017 stakeholders discussed the improvement of the continuity of messaging and branding throughout the Rhine watershed and

Figure 10.2

Rhine catchment visitor centres, where people can learn about biological diversity, observe migrating fish, connect to nature and understand the issues that fish face. Restoration work in the Rhine catchment is coordinated by the ICPR and agreed in the ICPR programmes Rhein 2020 and Master Plan Migratory Fish Rhine (www.iksr.org). © International Commission for the Protection of the Rhine (ICPR).



Afsluitdijk Wadden Center

The Afsluitdijk Wadden Center is being built at one of the river mouths of the Rhine, at the spill gates in the Afsluitdijk. At this location, the 4km long Fish Migration River will be built from 2019 until 2023. © De Nieuwe Afsluitdijk.



the importance of networking existing visitor

centres and adding experiences where there are gaps. An inventory of the many visitor centres at fish passage structures, wetlands and protected areas throughout the basin was made available to promote public interest in migratory fish (Figure 10.2). It is used to explain interdependencies with respect to ecological issues, water quality, floods and low water, and the communities around the river and to increase awareness of all these issues in the Rhine. A global map of visitor centres throughout the world is currently being developed by the World Fish Migration Foundation.

10.4.3 Education and outreach

To improve and protect robust populations of migratory fish, public support is required at

all levels from local citizens, anglers, farmers, governments and businesses, to national and international policy and legislative bodies. This requires educating and engaging with all people to improve their environmental awareness, provide information so they can advocate for the environment, catalyse local and regional action and change public perceptions, policy outcomes, and ultimately river health.

One of the challenges of migratory fish conservation is understanding what the current perceptions are, and how we can foster a more positive public understanding of fish and their environment. In many cases, there is a disconnect when it comes to riverine fish, for a large majority of citizens. This is partly because they are not easy to see and therefore not regularly, if ever on our minds. For many people the view of a river is beautiful enough, but there might not be an understanding that the river is not healthy or whole because the river is trapped between dams or levees or even a concrete channel. Most people do not consider fish as charismatic as, mammals and birds that offer a better sense of attachment. This ultimately informs judgements and actions (Takahashi, 2011). There are few aspects of fish physiology or behaviour that humans can relate to and in most cases the only time people encounter fish is either at the end of a fishing line or on a dinner plate.

One approach to improve positive attitudes toward fish is by promoting migratory fish for their utilitarian value; making the connection with food and recreation. Another way that has proven successful is to install flagship conservation programmes (Also see chapter 6 discussion on flagship species), assigning flagship status to a carefully selected fish species. There are a few examples where flagship status of fish species has led to an increased awareness and more easily associated with social and economic benefits (Gupta, et al., 2014). In Wales, UK, some politicians have agreed to act as "ambassadors" for iconic fish species including salmon, sea trout and brown trout, and to take special interest in their wellbeing. If there are improved attitudes toward migratory fish, there will be improved consideration toward incorporating their wellbeing into legislation and management plans.

Citizen education can be done through public awareness campaigns and outreach programmes. If communities are more informed, there is a much better chance of people caring and taking action. Building awareness and empowering people with information, encourages communities to stand up and provides them a voice and a platform. A EU survey in 2013 showed that one-fifth of EU citizens do not consider taking action to protect biodiversity, because they do not know what to do (European Commission, 2013). Another survey in 2016 indicated that 90% of EU citizens were not well-informed about fish biodiversity issues and were not familiar with many native and nonnative fish species (Kochalski, 2017).

There are many different ways to convey messages to the public. There have been many activities developed for the hundreds of World Fish Migration Day events that have effectively engaged and activated the public. This includes river clean-up campaigns, exhibitions, boat trips to visit fishing villages, conferences and workshops, public openings of fishways, river tours with visits to fishways, press articles, national news features, documentaries, social media campaigns, connecting with ambassadors, launching products, events at visitors centres and much more (World Fish Migration Day, 2016). Whatever the activity, the content, audience and approach should be a key consideration, and adapted for the appropriate audience, as discussed in Section 10.4.

Educating children is an incredibly important way to improve awareness of the general public and future leaders. They can be involved directly, but only after thorough consideration and application of any local statutes for working with children and ensuring appropriate safeguards. 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 consistently an extremely effective method of engaging and educating children, and demonstrably more long-lasting than simply providing written material on facts. An illustration of this in action includes games featuring salmon and eel developed for children. There are good examples in the USA (US Fish and Wildlife Services, 2016), Netherlands (Hunze en Aa's, 2012) and in UK (Bristol Avon Rivers Trust, 2017).

EIFAAC (European Inland Fisheries and Aquaculture Advisory Commission) concluded that in many parts of the world the education of commercial fishermen is necessary to ensure the future health of inland fisheries (FAO, 2000). This should include provisions for learning environmental and ecological information and, critically from a swimway perspective, this should include information on fish ecology and fish migration. EIFAAC also advised that information should be provided on the problems and threats fish face in their specific area, and the range of measures available to resolve these problems.

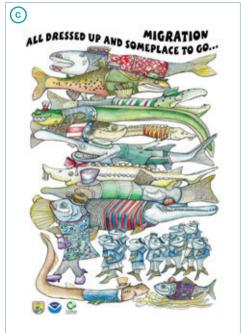
10.4.4 Citizen science and capacity building

In addition to education, it is equally important to clearly show the public how to take action and to encourage them to do so. Citizen science projects are a great way to involve the public in monitoring programmes, and there are many cases of this around the world. Some notable ones are those associated with eel monitoring in the Netherlands where citizens are invited to monitor eel migrations. There is a web app, where volunteers can upload the details of their bi-weekly monitoring surveys of glass eel migrations, for three months of the vear. at more than 50 sites across the country. These results are then used by local Water Authorities to make better decisions about where to focus management (Samen Voor de Aal, 2017). In England, a programme was designed and coordinated by the London Zoo, where hundreds of volunteers help to monitor eel populations within the Thames under an eel management plan (Zoological Society of London, 2016).

Learning made fun

A) The Fishway at pumping station Rozema (The Netherlands) allows fish to migrate inland from the Wadden Sea. There is a viewing room at the fishway, where the public is able to see the migrating fish. © Albert Jan Scheper. B) Lessons about fish species in a primary school in the Netherlands. © Ben Griffioen. C) All Dressed Up poster used during the USFWS fish migration campaign during 2016 WFMD event. © Laury Zicari/US Fish and Wildlife Service.





Inspiring people to get involved

A) Volunteers sampling glass eel in the Zuiderdiep during the project 'Samen voor de aal', a national scale citizen science project in The Netherlands. This is a cooperation between NGO's, Water Authorities, government, and community organisations, which facilitated an annual ongoing monitoring programme. It not only provides knowledge about migratory patterns to water managers, but also involves the community and continues to provide an excellent way to connect with the press © Nico van Kappel. B) European glass eel migrating inland at Scheveningen - monitoring by volunteers for the Samen voor de Aal project, Netherlands. © Lex Peters.





EXAMPLE

"Respect your elvers!": The Hudson River Eel Project

Author: Organisation:

Chris Bowser New York State Department of Environmental Conservation and Cornell University United States of America

Country:

ation a

INTRODUCTION

"Freshwater" eels migrate from oceans into freshwater estuaries and watersheds around the world, facing numerous challenges including over-harvesting, barriers to habitat access, and a negative perception from the public (Dekker & Casselman, 2014). In the Hudson River of New York State, a team of educators and scientists set up a monitoring program with three main goals: collect data on the annual migration of juvenile American eels (*Anguilla rostrata*), get eels above barriers, and build a community of "citizen scientists" who appreciate and even celebrate this unique species.

WHAT DID YOU DO?

In 2008, staff from the Department of Environmental Conservation Hudson River Estuary Program and National Estuarine Research Reserve, recruited high school students, teachers, and community volunteers to check fyke nets installed at two stream mouth sites. The volunteers were trained to follow protocols set up by the Atlantic State Marine Fisheries Commission as piloted in the early 2000's (ASFMC, 2000 and Schmidt *et al.*, 2006). This included daily checking of nets, carefully counting the transparent "glass eels" and larger "elvers", collecting basic environmental data, and releasing the eels above barriers to migration. The project expanded in a decade from two sites to fourteen. Since eels are found in almost any waterway from city creeks to rural brooks, there is a natural diversity of geography and audience.

WORKING WITH STUDENTS Showing a fresh catch of glass eels.



GLASS EEL RESEARCH

Students are checking the nets for transparent "glass eels" and larger "elvers".



Teams are engaged from the salty waters of New York City to over a hundred miles inland at the tidal freshwaters near Albany.

HOW DID IT WORK OUT?

The project was an instant hit: teachers and students loved the ecology lessons, community volunteers appreciated the chance to be involved in stewardship, and the public was intrigued by daily teams of volunteers wading into local streams. In 2017, over 850 volunteers from 45 partnering organizations and schools donated over 3,000 service hours, and in ten years the participants have caught, counted, and released a half-million eels upstream (Bowser, 2017).

The project has been promoted in newspaper articles, documentaries, book chapters, and conservation awards. Thousands of people have been educated through presentations, and the end-of-the season "eelebrations" are a fun way for volunteers and their families to appreciate the eel's remarkable achievement as well as their own.

LESSONS LEARNED

This project is very scalable. With support from regulatory agencies, safe access to appropriate sites, and a team of capable partners. American eels can be monitored in many rivers from Canada to Mexico, and is transferrable to related species elsewhere.

This project is also great at involving a wide range of communities that don't always have access to nature-based conservation efforts. Volunteers come from high schools, colleges, retirement communities, watershed groups, and interested individuals. Training and time is key, both to ensure accurate and safe data collection, and to reinforce in volunteers the science behind the stewardship.

The springtime arrival of tiny glass eels on a thousand-mile journey is a reminder that the connection from sea to source is in our hands, quite literally. Citizen science projects increasingly use advanced technology. A recent EU funded AMBER project is developing a mobile app that allows citizens to upload photos of barriers, which will then be used to record European barriers into a database (www.amber.international). There are also various online projects, where volunteers can help count fish passing through fish passages, such as Mystic herring project (https://www. mysticherring.org/video/welcome) and Vispotter project (http://www.visspotter.nl).

Involving people in restoration projects is a way to activate the public and give communities a sense of pride and ownership of their local environment. Talking and interacting with the public from the very conception of a restoration project, for instance the building of a fishway or removal of a dam, can be essential for the succes of the project as well as enriching lives of people engaged. If we communicate proactively, openly and honestly, the public can be a great ally. This is elaborated further in Section 10.3.

The provision of educational information in a formal educational syllabus at schools can be a very effective way to encourage the next generation to understand, build empathy, share ownership and to take action. Topics about the water cycle and the vital importance of water for the environment and society are important. The role of fish in aquatic ecosystems and the way in which flourishing fish communities demonstrate environmental quality are potent messages for society. In many cases the livelihoods of fishing communities, and the threats and challenges faced by migratory fish are important messages.

In addition to school education, developing expertise at colleges and universities is just as important. The limited education programmes that focus on topics on fish migration speaks to the need for improving:

- Practitioner's expertise through information sharing and collaborative research;
- Developing the skills to develop the functional collaborations needed for developing policy, removing a dam, or restoring an entire river basin;
- Building capacity for researchers, teachers and students through hands-on experience, new data, books, and online resources on fish migration and associated matters;
- Institutional development, including expansion of research areas at institutions.

LITERATURE

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Children carrying catfish in Cambodia ©Zeb Hogan.

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CONTRIBUTORS

THE

Field research team of the Karlstad University (Sweden) in action. © Herman Wanningen.

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AUSTRALIA

Ivor Stuart & John Koehn Arthur Rylah Institute for Environmental Research Ivor.Stuart@delwp.vic.gov.au John.Koehn@delwp.vic.gov.au

Lee Baumgartner Charles Stuart University Ibaumgartner@csu.edu.au

Martin Mallen-Cooper Fishway Consulting Services & Charles Sturt University mallencooper@optusnet.com.au

Matthew Gordos & Patrick Dwyer Department of Primary Industries - Fisheries matthew.gordos@dpi.nsw.gov.au patrick.dwyer@dpi.nsw.gov.au

Tim Marsden Australasian Fish Passage Services *Tim.Marsden@ausfishpassage.com*

BOLIVIA

Gustavo Rey-Ortiz Asociación FAUNAGUA gusreyortiz@gmail.com

Jaime Sarmiento & Soraya Barrera National Museum of Natural History, Fish Division jsarmientotavel@mnhn.gob.bo sbarreramaure@mnhn.gob.bo

BRAZIL

Alexandre Sorokin Marçal Ecofish Research alexsmarcal@gmail.com Angelo Antonio Agostinho, Anielly Galego de Oliveira, Mirtha Amanda Angulo Valencia, Rafaela Giacomel Rauber & Rosa Maria Dias State University of Maringá agostinhoaa@gmail.com anielly_oliveira@hotmail.com dusam009@hotmail.com rafaelagrauber@outlook.com rmdias2003@yahoo.com.br

Carlos Bernardo Mascarenhas Alves Bio-Ambiental Consulting *cbmalves@gmail.com*

Hugo Marques hugo@fishtag.com.br Fishtag Consultoria Ambiental

João de Magalhães Lopes Applied Ecology Graduate Program - UFLA jaolopes@hotmail.com

João Henrique Pinheiro Dias São Paulo State University *jhdias.bio@gmail.com*

Paulo S. Pompeu Federal University of Lavras Pompeu@dbi.ufla.br

Jonas Kilpp, Leonardo Machado, Leonardo Nunes, Lisiane Hahn, Luís Fernando da Câmara, Marina Granai & Taise Miranda Lopes Neotropical Consultoria Ambiental jonas@neotropical.com.br leonardo@neotropical.com.br leonardo@neotropical.com.br lisiane@neotropical.com.br ffc@neotropical.com.br marina@neotropical.com.br

Ronaldo Borges Barthem Museu Paraense Emílio Goeldi-Campus de Pesquisa-CCTE barthem@superig.com.br

CHINA

Hui Zhang Yangtze Aquatic Research Institute, China Academy of Fisheries Science dingo-zh@163.com

Luhong Wang The Nature Conservancy China Program Luhong.wang@TNC.ORG

FRANCE

Gilles Segura CNSS g.segura@cnss.fr

ETHIOPIA

Abebe Getahun Addis Ababa University, Department of

Zoological Sciences abebe12002@yahoo.com

Eshete Dejen Intergovernmental Authority on Development eshetedejen@gmail.com

Wassie Anteneh Bahir Dar University, College of Science, Department of Biology wassie74@gmail.com

IRELAND

Kieran Mc Carthy Ryan Institute, National University of Ireland Galway *tk.mccarthy@nuigalway.ie*

ITALY

Barbara Belletti, Simone Bizzi POLIMI barbara.belletti@polimi.it simone.bizzi@polimi.it

Wouter van de Bund European Commission DG Joint Research Centre *Wouter.VAN-DE-BUND@ec.europa.eu*

JAPAN

.....

Keiko Muraoka Public Works Research Institute muraoka@pwri.go.jp

Shinji Fukuda Tokyo University of Agriculture and Technology *shinji-f@cc.tuat.ac.jp*

Shoko Tsuru An Association to Revive the rich Kumagawa River *tsuru-shoko89314@hiz.bbiq.jp*

NETHERLANDS

Bart Geenen WWF Netherlands bgeenen@wwf.nl

Bruno Doedens Stichting Landschapstheater en Meer bruno@slem.org

Diederik van der Molen Ministry of Infrastructure and Water management *diederik.vander.molen@minienm.nl*

Erik Bruins Slot & Roef Mulder Province Fryslân e.bruinsslot@fryslan.frl r.mulder@fryslan.frl Herman Wanningen, Joost van Deelen, Kerry Brink World Fish Migration Foundation *Herman@fishmigration.org Joostvandeelen@eurofins.com Kerry@reachingrivers.com*

Jeroen Huisman & Paddy Walker Van Hall Larenstein Applied Sciences University Jeroen.huisman@hvhl.nl paddy.walker@hvhl.nl

Jeroen van Herk & Wilco de Bruijne OAK consultants jeroen@oakconsultants.nl wilco@oakconsultants.nl

Jos de Bijl Regional Water Authority Delfland jdebijl@hhdelfland.nl

Katja Philippart Waddenacademie katja.philippart@waddenacademie.nl

Koen Workel, Marc de Rooy & Pieter Beeldman Ministry of Infrastructure and Water management koen.workel@rws.nl Marc.de.Rooy@minienm.nl pieter.beeldman@rws.nl

Niels Brevé Sportvisserij Nederland breve@sportvisserijnederland.nl

Marius van Wingerden Regional Water Authority Scheldestromen marius.vanwingerden@scheldestromen.nl

Martha Buitenkamp Anantis *m.buitenkamp@anantis.nl*

Peter Paul Schollema Regional Water Authority Hunze & Aa's p.schollema@hunzeenaas.nl Rik Beentjes Regional Water Authority Hollands Noorderkwartier *r.beentjes@hhnk.nl*

Michiel Firet & Wim Schoorlemmer Programma naar een Rijke Waddenzee *m.firet@staatsbosbeheer.nl w.j.schoorlemmer@minez.nl*

NEW ZEALAND

Katharina Doehring Cawthron institute Kati.Doehring@cawthron.org.nz

Paul Franklin National Institute of Water & Atmospheric Research (NIWA) Paul.Franklin@niwa.co.nz

PORTUGAL

José Maria Santos Forest Research Centre, School of Agriculture, University of Lisbon *jmsantos@isa.ulisboa.pt*

RUSSIAN FEDERATION

Dmitrii Pavlov A.N. Severtsov Institute of Ecology & Evolution, Russian Federation *pavlov@sevin.ru*

SOUTH AFRICA

Byron Grant Ecology International byron@ecologyinternational.net Cate Brown Institute for Water Studies, University of the Western Cape & Southern Waters cate@southernwaters.co.za

Garth Wellmen Caleco Capital Garth@Caleocapital.com

Gordon C. O'Brien & Matthew Burnett University of KwaZulu-Natal *Obrieng@ukzn.ac.za* matthewbuhome@gmail.com

Jackie King Institute for Water Studies, University of the Western Cape & University of the Western Cape jackie.king@watermatters.co.za

Navashni Govender, Robin Petersen & Stephen Midzi South African National Parks Navashni.govender@sanparks.org Robin.Petersen@sanparks.org stephen.midzi@sanparks.org

Olaf Weyl South African institute for Aquatic Biodiversity *O.Weyl@saiab.ac.za*

SPAIN

Francisco J. Oliva Paterna. Department of Zoology. University of Murcia. 30100. Murcia. *fjoliva@um.es*

Francisco J. Sanz Ronda U.D. Hidráulica e Hidrología. ETS.II.AA. Palencia. University of Valladolid. escalasparapeces@gmail.com Gustavo González Icthios Gestión Ambiental S.L. & Centro Ibérico de Restauración Fluvial (CIREF) *gustavo@icthios.es*

Marc Ordeix Center for the Study of Mediterranean Rivers (CERM), University of Vic - Central University of Catalonia marc.ordeix@museudelter.cat

Pao Fernández Garrido & Rosa Olivo del Amo World Fish Migration Foundation (WFMF) Pao@fishmigration.org rosa@fishmigration.org

SWEDEN

Daniel Nyqvist, Olle Calles & Stina Gustafsson Karlstad University Olle.calles@kau.se daniel.nyqvist@kau.se stina.k.gustafsson@lansstyrelsen.se

SWITZERLAND

Jürg Bloesch International Association for Danube Research Juerg.Bloesch@emeriti.eawag.ch

UNITED KINGDOM

Carlos Garcia de Leaniz, Joshua Jones & Luca Börger, Swansea University c.garciadeleaniz@swansea.ac.uk J.A.H.Jones@Swansea.ac.uk I.borger@swansea.ac.uk

Jeroen Tummers Durham University j.s.tummers@durham.ac.uk Jim Kerr & Paul Kemp Southampton University J.Kerr@soton.ac.uk p.kemp@soton.ac.uk

Mark Lloyd Angling Trust mark.lloyd@anglingtrust.net

Mike Morris Severn Rivers Trust mike@severnriverstrust.com

Peter Gough World Fish Migration Foundation (WFMF) Peter@fishmigration.org

Stephen Marsh-Smith The Wye and Usk Foundation stephen@afonyddcymru.org

UNITED STATES OF AMERICA

Alex Haro, Benjamin Letcher, Stephen McCormick & Theodore Castro-Santos U.S. Geological Survey (USGS) Alex_Haro@usgs.gov bletcher@usgs.gov smccormick@usgs.gov tcastrosantos@usgs.gov

Bob Irvin American Rivers *birvin@americanrivers.org*

Catherine Schmitt & Stephen M. Coghlan Jr. University of Maine catherine.schmitt@maine.edu Stephen_Coghlan@umit.maine.edu

Chris Bowser New York State Department of Environmental Conservation and Cornell University chris.bowser@dec.ny.gov Daniel Cenderelli USDA Forest Service, National Stream & Aquatic Ecology Center, Fort Collins, CO dcenderelli@fs.fed.us

Joshua Royte & Erik Martin The Nature Conservancy jroyte@tnc.org emartin@TNC.ORG

George Pess United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA george.pess@noaa.gov

John Waldman Queens College, CUNY john.waldman@qc.cuny.edu

Joseph Encinas USDA Forest Service, WFWARP Staff, Washington, DC jencinas@fs.fed.us

Laura Wildman Princeton Hydro *lwildman@princetonhydro.com*

Mark Weinhold USDA Forest Service, White River National Forest, Golden, CO *mweinhold@fs.fed.us*

Matt Boyer Montana Fish, Wildlife and Parks MBoyer@mt.gov

Michele Thieme WWF USA michele.thieme@wwfus.org Nathaniel Gillespie USDA Forest Service, Fisheries Staff, Washington, DC ngillespie@fs.fed.us

Robert Bauer Chelan County *Robert.Bauer@chelanpud.org* Robert Gubernick USDA Forest Service, Region 9 Technical Services Team, Duluth, MN *rgubernick@fs.fed.us*

Teresa Campbell & Zeb Hogan Global Water Center, University of Nevada, Reno tcampbs@gmail.com zhogan@unr.edu

William Rice US Fish and Wildlife Service National Fish Passage Program william_rice@fws.gov

ZAMBIA

Bruce Ellender South African Institute for Aquatic Biodiversity bru.ellender@gmail.com

Sililo Agness Musutu WWF Zambia amusutu@wwfzam.org

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