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D4.1 - Review of benefits, challenges, and trade-offs in adaptive barrier management (Best Practice Report)

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The opinion stated in this report reflects the opinion of the authors and not the opinion of the European Commission.

Executive summary

This is the 1.0 version of the Best Practice Report on Adaptive Management of Barriers. This document is a deliverable of the AMBER project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689682.

This report reviews Adaptive Management (AM) in the context of barriers in rivers/streams, highlighting both benefits and challenges of implementation. The report provides specific examples of successes and failures of using AM in countries across Europe. Using the "lessons learned" from various case studies, we provide recommendations on Best Practice for the successful use of AM.

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1 INTRODUCTION

1.1 Context: barriers in freshwater ecosystems

Freshwater ecosystems are in a poor state worldwide. Despite their economic importance, freshwater systems continue to be overexploited and susceptible to anthropogenic activities (Cowx 2002; Saunders *et al*. 2002). While they represent less than 1% of the world's surface, they are home to more than 126 000 species (IUCN 2016), and provide a large number of ecosystem services (e.g., work, recreational activities, power etc.). One of the most severe threats to these ecosystems are artificial barriers.

Originally developed to maintain trading routes, acquire food and to regulate water flow as a means of generating energy, barriers now come in a variety of forms – hydrodams, weirs, culverts, sluices, etc. – and their distribution and abundance continue to increase. More than any other habitat, freshwater ecosystems have been modified and used to meet human needs; this has left them in a deplorable state (Jungwirth 1998; Jager *et al*. 2001), with huge reductions in habitat quality and biodiversity. Due to the loss of longitudinal connectivity that such species depend on to complete their lifecycle, these ongoing threats are especially challenging for mobile biota, fish in particular (Arthington *et al*. 2016).

One of the most obvious effects of barriers is to block movement. Results from extensive studies demonstrate obvious impairments: complete blockage, delays, injuries, excess energy expenditure and more (Poe *et al*. 1991; Jepsen *et al*. 1998; Lucas and Baras 2001; Bunn and Arthington 2002; Aarestrup and Koed 2003). These direct consequences can lead to reduced success in reproduction and migration and reduced survival via increased predation or delayed mortality from sustained injuries. However, barriers can have other, less direct, consequences. One of the, often forgotten, consequences of barriers is the way in which they alter habitats (Birnie-Gauvin *et al*. 2017a). By slowing the flow of water, increasing water depth, increasing sedimentation and changing the bottom substrate from gravel to mud, barriers essentially remove all suitable spawning and early-development habitat upstream of the impoundment. Therefore, even if fish are successful in overcoming a barrier, the odds of adult fish successfully reproducing and of eggs developing, are low. It is estimated that barriers account for 55 to 60% of the known causes leading to freshwater fish becoming endangered (Northcote 1998). The management of such barriers is therefore important in deciding the future state of freshwater ecosystems.

1.2 European perspective

Europe has a large number of shorter slow-moving rivers than anywhere else in the world. While Europe does have large rivers, it has many more small rivers than large ones, but little attention has been given to the former. Managers cope with highly variable freshwater ecosystems in Europe (Gough *et al*. 2012), and management is further complicated by the number of countries concerned (50), each of which manage their freshwater ecosystems slightly differently. Some nations have adopted a "removal as first option" approach to barriers, (though Denmark is the only country we are aware of with this strategy), while others are still building them (e.g., Spain, Poland, Italy, Lithuania).

While Europe does have a number of large barriers (e.g., Poutès Dam, Pitlochry Dam), small barriers are much more abundant. Many of these barriers no longer serve a functional purpose, but remain in place because their presence remains unnoticed due to poor national inventories or because the barriers have a cultural/heritage value.

Since 2003, every member of the European Union has had to abide by the rules outlined in the Water Framework Directive (WFD). The WFD outlines the presence of man-made barriers/loss of connectivity as one of the main pressures that it aims to reduce. In addition to this, each country has its own set of rules, guidelines and environmental agency/managers, often approaching barrier management differently. It would therefore be difficult to, for example, manage a barrier in Poland using an approach that was successful in Ireland.

2 ADAPTIVE MANAGEMENT

2.1 What is Adaptive Management?

Adaptive Management (AM) is a way to structure and implement decision-making processes for the management of both species and natural areas.

The idea of AM developed from the acknowledgement that ecosystem management and conservation is a dynamic and unpredictable process. Therefore, to achieve management objectives, we need to modify and update practices as knowledge evolves (Holling 1978; Lindenmayer and Burgman 2005; Westgate *et al*. 2013). Such an approach is particularly appropriate when dealing with ecological resources, which are dynamic in nature; and would therefore be an appropriate method when managing barriers (for example management of flow characteristics - see Baumgartner *et al*. 2014; Summers *et al*. 2015). This dynamic conservation approach has grown greatly since the seminal work of Walters and Hilborn (1976) and Holling (1978), and is considered fundamental to sustainable practices (Westgate *et al*. 2013; Williams and Brown 2014). An adaptive approach requires extensive planning, an active and systematic effort to gather and document information, and the early involvement of stakeholders in the decision-making process (Lindenmayer and Burgman 2005). There are four fundamental elements to AM, as identified by Davis *et al*. 2001: (1) acknowledging the uncertainties associated with management policies, (2) formulating management policies as testable hypotheses, (3) searching, using and assessing information in order to test hypotheses, and (4) adapting management policies periodically as new information is acquired.

In the management of natural systems (Adaptive Nature Management) the concept of AM as described in Williams *et al*. (2009) has proven very helpful in the process of drafting and developing management plans for given species or areas. In the European Union (EU) the concept has been successfully applied in drafting an EU-wide management plan for pink-footed geese (Madsen *et al*. 2017).

Issues and objectives are clearly formulated through dialogue and cooperation between relevant stakeholders, citizens, managers and researchers. Such interest groups also need to agree on potential initiatives that could lead to the fulfilment of agreed objectives.

During the subsequent implementation of a given project, which typically extends over a number of years, the group regularly monitors, evaluates and - if necessary – adjusts the actions relative to the objectives. Scientists often develop modelling tools that predict how the system (for example, population development or state of nature) will respond to any initiatives. The models adjusted when new insights are gained.

This approach gradually narrows down uncertainties about the system and the response to initiatives, everyone has an opportunity to learn during the process, and, since all parties are involved, there are better opportunities for building trust and gaining greater commitment.
Adaptive nature management may be particularly useful in situations in which value-based conflicts of interest and competing needs have to be resolved. However, we would argue that AM is a slow process, despite sometimes being advertised otherwise, and may not be suited to situations where a "quick decision" is needed.

An adaptive but structured approach to nature management requires new forms of cooperation and ways of thinking, therefore there is a strong need to develop and disseminate the concept and instruct stakeholders in the use of adaptive management.

From Williams *et al* (2009) AM is described as: "*Adaptive management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders.*"

Traditional engineering/natural science thinking often assumes that natural elements interact in a predictable manner; in many ways, the concept of AM runs contrary to this. AM acknowledges uncertainty in the way natural resource systems function, and in how they respond to management actions; it should improve the understanding of how a resource system works, and help achieve management objectives. To do this, AM makes use of management measures and monitoring to promote understanding and improve subsequent decision-making. A management plan laid out according to these principles should, therefore, not only reduce conflicts and promote good decisions but also ensure more specific knowledge about the questions in focus.

There is an increasing tendency to treat conservation as a business, with a mandate for efficiency and accountability, this requires a systematic approach to decision-making and clear performance measures to evaluate the effectiveness of actions.

Part of the difficulty in realizing this vision, seems to be that conservation practitioners sometimes forget ***that conservation is primarily a human enterprise rather than a scientific one***, where people must define what constitutes desirable outcomes. Like all decision-making, conservation involves predicting the outcomes of alternatives, and then evaluating those outcomes. While the former is the objective role of scientists, the latter is the subjective role of decision makers (and ultimately of society). In management, there is often a small group of people with a strong objective interest in one particular outcome on one side, while on the other there is a large or very large group of people with a rather weak or subjective interest in another outcome. For example in the case of wolf management, there is a small group of (sheep) farmers with a very strong and objective interest in regulating the wolf population, and a very large group of people with a subjective interest (wild and varied nature), and the need to consider threats to biodiversity and international obligations to protect species like the wolf. So here, we have to balance very different perspectives/interests in order to ensure effective management. One option is to use an AM-process.

In the case of barrier management, "hard" data on cost/benefit is normally readily available on the dam-project, whereas there is little or no data on the impact on the ecosystem or even individual resources/species, despite the fact that this impact can be very important. This bias in data availability makes communications between two sides (dam builders and nature protection/conservation groups) very difficult and long-lasting conflicts often arise. Once a political decision is made and a dam is constructed, the conflict remains "cast in concrete" for a long time. These conflicts re-emerge when a decision needs to be made about whether to **remove or restore** the increasing number of dams and barriers becoming old and in many cases non-operational. In such situations, it would be sensible for managers to apply the AM process outlined in Birnie-Gauvin *et al*. 2017b. In the case of dam building or removal, the cyclic part of AM may seem obsolete, but prior to making the decision it is important to adjust the project plans according to new evidence and new input from interest groups. Once the dam is removed or built, the management is more or less finished, but in both cases, it is very important to continue monitoring the consequences and keep the AM-infrastructure (stakeholder group) in place. There are two benefits to doing this; 1) Information about the consequences of the project will lead to better general knowledge that can be applied in similar conflicts, 2) continuous communication between stakeholders, including authorities, will greatly reduce the risk of new conflicts emerging.

While the use of AM in barrier management is very rare and/or rarely reported (Birnie-Gauvin *et al* 2017b), there are examples where at least some elements of the AM process have been used successfully and (many more) examples where solutions would have been much better if a more participatory approach had been used. In many cases, the under-reporting of AM processes in the context of barriers makes it difficult to develop meaningful analyses about how efficient the process is in "the big picture". In many instances where AM is used, reports are presented in the native language of each country, making it very difficult for any other country/organization to learn from them.

2.2 Benefits & challenges

Many of the benefits and challenges of using AM were introduced in section 2.1, in this section we will focus on those benefits and challenges by putting them into context using specific examples.

2.2.1 Benefits

One of the biggest benefits of AM is its use of regular reviews of effectiveness and progress of measures currently in place in a given river system. For example in England, to ensure compliance with the (WFD), the government-sponsored Environment Agency (EA) conducts regular fish community surveys as one of the biological quality elements of its program. This identifies sites with depauperate fish communities. In combination with habitat assessments, adaptive management of barriers downstream of such sites may result in the restoration of fish communities and the wider ecological integrity of the (sub) catchment, potentially lifting a river into good ecological status as required by the WFD. This regular monitoring – a requirement of AM – allows for adjustments in objectives and management strategies.

Temporal changes in the chemical and/or biological quality status of (sub) catchments can affect fish communities. In England, the EA uses fish presence/absence in their ecological stream assessment. An AM approach can be effectively used to restore the ecological conditions of the affected reach following a pollution incident, which may influence fish communities, by targeting barriers downstream of the pollution site, and/or ones that restrict longitudinal connectivity the most.

Modelling (an important tool used in AM), is essential in understanding how environmental factors may influence a system, and in predicting the outcomes of various management options (Thom 2000; Bearlin *et al*. 2002). This approach helps to integrate future unexpected events by guiding the development of predictions and hypotheses - especially relevant in today's changing world. In the context of barrier management, modelling of dendritic river connectivity may identify barriers where management is most cost-effective in terms of restoration gains. AM can thus allow river managers, with a limited budget, to target those barriers that will improve connectivity.

Stakeholder engagement is a crucial aspect of AM and from an environmental perspective can be viewed as both a benefit and a challenge. For example, in Denmark, Hjerritsdal Mill in Valsgård stream was initially built in 1541, and remains one of the most unspoiled medieval mills found in Denmark. The mill is no longer in use, and its presence creates a ponded zone of approximately 100m. This zone is difficult for brown trout to navigate, and, in addition, in order to migrate they have to overcome a weir/fish ladder. While environmental organizations, whose priority is conservation, need to be included in the decision making process, the mill cannot be removed because it represents cultural heritage. AM was used to try to reconcile the needs and wants of all stakeholders. Both the environment agency and the culture agency agreed that a complete bypass of the pond would be the best solution. However, the owner of the land on which the bypass would need to be built felt that this would cause unsurmountable problems for his cattle in passing from one end of the field to the other. The solution was to build a bypass around the weir rather than around the entire pond, meaning that fish must still pass through the pond, a solution that improves situation for the fish but is not ideal. AM can help in reconciling widely differing opinions, but can sometimes come at a cost to nature (and sometimes that cost means not fulfilling the primary reason of the initiation of AM).

2.2.2 Challenges

There are four main challenges with AM: 1) reconcile stakeholder perspectives, 2) adequate surveying/monitoring, 3) permissions/authorizations and 4) money.

As discussed above, stakeholder engagement is seen as one of the advantages of using AM, but reconciling sometimes widely disparate perspectives and opinions is a difficult task, meaning that successful AM can be difficult or, in some cases, impossible to achieve. A common caveat in AM is that it causes resource management problems because of the way it manages human motivation (Ludwig *et al*. 1993), especially when the main concern should revolve around the resource itself. Stakeholders can be unwilling to compromise and/or accept change, resulting in serious delays in management efforts, or even completely stalling the process.

Most EU member states have an agency that performs ecological assessments; with varying bureaucratic processes to be followed before AM can be undertaken. Using the EA in England as an example:

The EA's undertakes ecological stream assessment based on fish abundance (Fisheries Classification Scheme 2 (FCS2)), which encompasses fish abundance, taxonomic composition and age structure. The number of salmon and trout surveyed is compared to the predicted abundance and prevalence of the species at the specific site, taking into consideration habitat characteristics including hydrogeomorphology, altitude and gradient. If the survey site is inadequate because of spatial (e.g. in an unobstructed reach close to the river's sink), or temporal (e.g. single surveys without inter-seasonal repeats over multiple years), reasons, a (sub) catchment may be classified as of 'good' ecological status where, in fact, most of the river system is severely fragmented with poor ecological conditions. Assessments should be performed in areas that are representative of the overall ecological situation

and in the case of dams/weirs should be both upstream and downstream of barriers; but too often, this is not the case. Related to this is fact that employee turnover and the development of new techniques mean that the method/approach used can often be inconsistent over time, affecting the results used to adapt management strategies.

Once a barrier has been identified and an AM approach is advised, permissions and authorisations for barrier removal or fishway implementation have to be gained, these must comply with the Wildlife and Countryside Act (1981), the Land Drainage Act (1991), the Water Resources Act (1991), the Environment Act (1995) and EC directives. In the case of technical fishways in England, the National Fish Passage Panel (NFPP) considers and makes recommendations to the EA for formal authorisation (Armstrong et al., 2010). Taken together, this bureaucratic, iterative process of barrier management legislation may take a lot of time and is further complicated by landowner permissions, designations of different water bodies within a (sub) catchment, County Council regulations and budgetary constraints.

In other member states, landowner and municipality can undertake the process of making a decision on barrier removal/mitigation alone. The bureaucracy involved in decisions about barriers thus varies greatly between member states. However, as can be seen from the Belmontas case (see 3.4 below), even modest barriers can be the centre of intense conflict on a national level.

Sometimes the problem is considered too marginal to initiate a costly and lengthy AM process – the cost would outweigh the benefits. A possible solution is to approach the entire river system rather than individual barriers as one management unit. In catchment management, barriers in small lowland streams are often disregarded and viewed as obstacles with no impact, and their combined effects are largely underestimated (Tummers *et al*. 2016a; Birnie-Gauvin *et al*. 2017a). In many instances, more emphasis is placed on the measureable economic interests of stakeholders than the (often-unmeasurable) conservation problems at hand, thereby slowing the process of experimentation, learning and adaptation. Management becomes stuck at the modelling step because research is deemed too expensive, which comes at the cost of ecological sustainability.

AM can be a costly process: stakeholder meetings and discussions; performing adequate surveying; filing the bureaucratic papers necessary to initiate management solutions; and performing continuous monitoring to ensure proper management of the resource (what AM is all about) is costly. In the case of large barriers, compared to the costs of construction and maintenance, the costs of AM are dwarfed. On a smaller scale, i.e. small weirs, the costs of AM often exceed those of removing/mitigating/maintaining.

3 EXAMPLES OF ADAPTIVE MANAGEMENT: SUCCESSES AND FAILURES

3.1 Old Durham Beck, England

Inadequate ecological assessments hinder adaptive management opportunities at stream barriers: the case of a stream network in North East England

Restoring impacted river systems requires adequate survey approaches to assess the ecological integrity of the catchment, including constituent sub-catchments, to target improvements for greatest

ecological benefit at lowest economic cost (Azimi and Rocher, 2016; Perkin and Bonner, 2016; King *et al*., 2017; Erős *et al*., 2018). The EU WFD (WFD, Directive 2000/60/EC; EC, 2000) requires the ecological condition of constituent georeferenced 'water bodies' to be measured, classified relative to reference conditions, and reported on schedule for meeting 'Good Ecological Status' targets by, at the latest, 2027. The impacts of stream and river barriers on ecological connectivity can be measured in many ways (e.g. by measuring genetic isolation of native metapopulations divided by structural barriers (Bracken *et al*., 2015; Pavlova *et al*., 2017; Coleman *et al*., 2018)). However, many EU states including England and Wales rely to a large extent on their national inventories of WFD biological and chemical monitoring of water bodies in order to target and prioritise ecological improvements locally (Hering *et al*., 2010; Tummers *et al*., 2016a). In England and Wales, much of the river restoration work is now done by the 'third sector', constituting Rivers Trusts, Wildlife Trusts and other NGOs. While these are acknowledged to be economically efficient in delivering ecological improvement schemes (Boon and Raven, 2010; Mainstone and Holmes, 2010), state funding of such projects in England and Wales occurs almost exclusively only for water bodies failing WFD assessment, using the biological and chemical sampling methods referred to above. Moreover, in England and Wales such decisions are, almost exclusively, based upon the outputs of governmental WFD sampling activities whether well organised or inherently flawed.

While several taxa such as benthic macroinvertebrates and diatoms may be good indicators of water quality (Kelly *et al*., 1998; Armitage, 2000), fish communities are influenced by water quality but also by stream connectivity and habitat (Pont *et al*., 2006; Birnie-Gauvin *et al*., 2017a). With an appropriate spatial and temporal survey framework in a sub-catchment, the spatial pattern of fish community characteristics may allow inference of stream barrier impacts on the fish community and resultant ecological condition. Where a WFD-georeferenced 'water body' fails to achieve 'Good Ecological Status' or 'Potential', the State's statutory body (Environment Agency in England) must seek to identify the cause and address it in order to improve the water body's ecological status for the failing biological or chemical elements. One of the most common causes for 'fish' biological element WFD failures is due to hydromorphological alteration (Reyjol *et al*., 2014), commonly including various instream barriers, reflecting the importance of stream connectivity and appropriate habitat for natural fish communities (Tummers *et al*., 2016a; Silva *et al*., 2018). As a result, the spatial and temporal scale of fish sampling in WFD water bodies, relative to potential barriers and habitat modifications, is crucial for representative measurement of the fish 'biological element' (the same applies, but perhaps to a lesser degree, for other biological elements such as macroinvertebrates).

Our experience in England and Wales is that WFD fish sampling may not always use appropriate spatial (i.e. multiple survey locations along the longitudinal gradient of a catchment, and accounting for the dendritic pattern of the system) and temporal (i.e. multiple repeat surveys, at standardized periods in the year with similar intervals) scales. With regards to highly-mobile aquatic biota such as fish, survey locations should reflect community metrics along the catchment (or sub-catchment), especially in a heavily modified catchment with a high density of in-stream structures, which may dramatically reduce longitudinal connectivity dependent on structure characteristics, flow conditions and fish morphology. Poor sampling strategy can result in biased outcomes, flawed interpretation and failed opportunities for the proper use of an AM approach for reducing the ecological impact of river barriers, while taking due account of socio-economic drivers. In the worst cases, statutory agencies can rate one or more water bodies in a sub-catchment as of 'Good Ecological Status' and then apply a rule that effectively (unwittingly) blocks investment in local river restoration, often against the opinions of other local stakeholders.

Old Durham Beck (ODB) is a first-third order tributary of the River Wear (catchment area of 1080 km2 and main stem ca. 97 km long) in North East England (**Figure 1**), and joins the Wear in its lower reaches.

ODB comprises three WFD-listed water bodies. The Wear catchment area has a pollution history predominantly caused by extensive mining activities that intensified from the mid-17th century but have declined since the mid-20th century, aggravated by urban and industrial infrastructure development, especially in the lower catchment area, including ODB. From the industrial revolution until the early 1960s, Atlantic salmon (*Salmo salar*) and sea trout (anadromous *Salmo trutta*) stocks in the Wear declined (and became almost extinct). However, they are now are recovering in many rivers in North East England, including the Wear (Russell *et al*., 1995; Environment Agency (EA), 2018a), largely as a result of water quality improvements in the lower river and estuary, and fish passage provision on the main river.

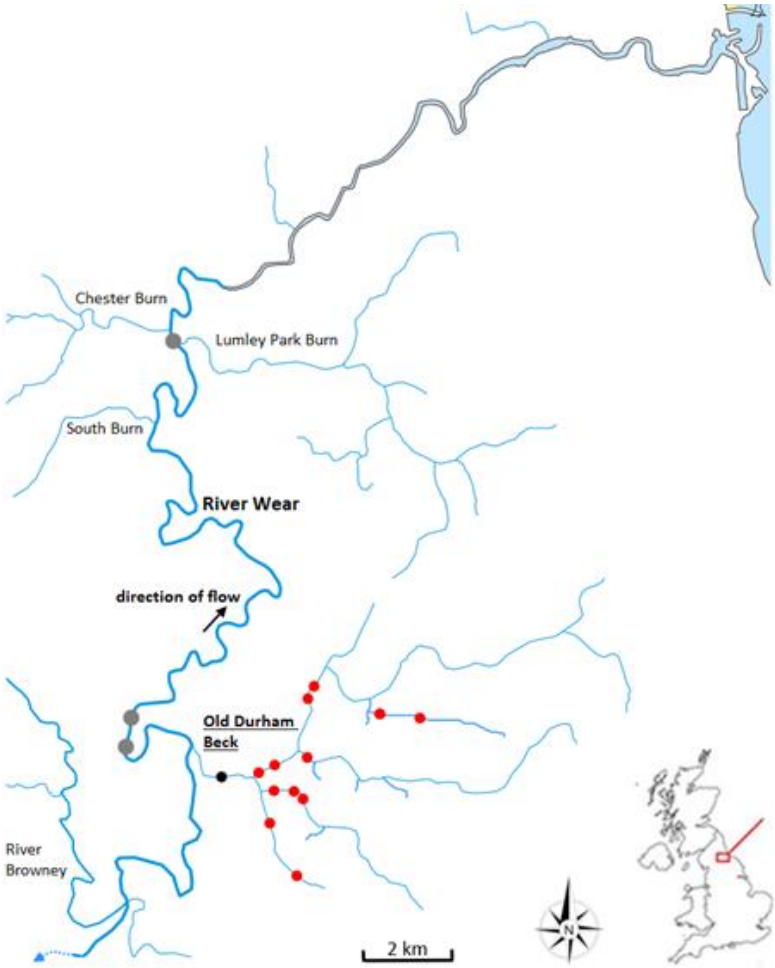

Figure 1. Location of the EA's sole survey site (marked with a black dot) on ODB, along with identified pipe culverts (red dots) and further obstructions (with fish passes) to fish movement on the main River Wear downstream of the confluence with ODB (grey dots).

Chemical water quality in ODB was classified as good (in compliance with the WFD), in all three of its constituent water bodies, ecological status was good for the downstream water body, but poor/moderate for the remaining water bodies (EA, 2018b). Since the EA's sole survey site for WFD fish metrics on this sub-catchment is located 0.75 river kilometres (RKm) from its confluence with the Wear, the biological quality element 'fish' is absent in assessment scores for the middle and upper

water bodies. Remarkably, there are no in-stream structures in between this survey site and the Wear, but the rest of the sub-catchment is considered, (by the authors), to be heavily fragmented by at least 12 low-head obstructions (flow-regulating pipe culverts - **Figure 1**). There are also at least 13 more in-stream structures present in the sub-catchment in the form of non-flow-regulating box culverts, bridges etc.). Scientific fish community surveys (Tummers, 2016) directly downstream and upstream of (chiefly) the pipe culverts showed significant differences in fish densities per species, often with higher fish densities and fish species richness observed below the respective structures. Fish densities downstream and upstream were generally lower than at reference sites, and fish assemblages were generally very depauperate or absent in the headwater areas of streams. Shannon-Wiener indices showed a significant difference downstream compared to upstream of structures, this effect was greater than at other streams located nearby, but with lower in-stream structure density and numbers. This indicates a stronger fragmentation effect on ODB than on the other streams studied (Tummers, 2016).

As obstacle, removal or modification is less effective if no habitat suitable for spawning, nurseries, feeding or seeking shelter is available in the reach to be opened up, degraded habitat quality may have a bottleneck effect on restoring the ecological integrity in previously fragmented reaches (Birnie-Gauvin *et al*., 2017a). Fortunately, habitat quality (based on macro-invertebrate sampling and river habitat assessments for each survey site) in ODB was classed as good in the lower and middle reaches of the sub-catchment (Tummers, 2016). Thus, opportunities for adaptive management in ODB do exist in the form of obstacle removal, modification or retrofitting of fishways. These may facilitate the recovery of fish communities and (re)colonization of fishes throughout this impacted system (including the economically important Atlantic salmon, and the anadromous morphotype of brown trout, which have been recorded in increasing numbers over the last decades in the lower Wear (Mawle and Milner, 2003; EA, 2018c)). However, the single fish survey site on this sub-catchment as used by the EA biases the resulting catchment classification because:

- The location of the survey site, and number of EA (official WFD agency) sites, are inadequate; these should be located throughout the sub-catchment at multiple locations conforming to the dendritic stream pattern, not only near the stream sink.
- The absence of structures between the survey site and the stream sink is not representative of the level of fragmentation in the remainder of the sub-catchment.
- While the EA has a theoretical mechanism for considering third party WFD evidence, the data within Tummers (2016), despite comprising an extensive sampling framework and rigorous statistical analysis, have failed to convince EA of the need to re-evaluate whether ODB meets 'Good Ecological Status' for fish.

The EA's ecological stream assessment based on fish presence/absence (Fisheries Classification Scheme 2 (FCS2)) encompasses fish abundance, taxonomic composition and age structure, and relates the number of species surveyed to the predicted abundance and prevalence of the species at the specific site, considering habitat characteristics including hydromorphology, altitude and gradient. In a heavily fragmented system such as ODB, highly mobile species such as Salmon and Trout may not be able pass the many structures and were absent in the middle and upper reaches (Tummers, 2016), but both these species were recorded in moderate to high numbers in EA's fishing surveys near the Wear confluence (EA, 2018b).

There are opportunities for improving ecological quality throughout the sub-catchment by restoring the impacted reaches in ODB. However, the inaccurate outcome of the 'fish' element of the ecological classification status results in ODB not to be considered eligible for connectivity restoration funding, (connectivity and/or physical habitat are among the most common causes in 'fish' element failures -

undoubtedly applicable to ODB). This hinders the assignment of EA restoration priorities to this sub-catchment and impedes restoration efforts by river managers. It also hinders effective cooperation and restoration activities on ODB by third sector groups such as the Wear Rivers Trust. As such, it has not, thus far been possible to achieve an effective evidence-based AM Process regarding barrier management, which incorporates ecological enhancement needs. If AM is to be applied effectively to river barriers across the EU, our wider lesson and hope, from this case study, would be that the national agencies responsible for WFD metrics and ecological improvements take a more inclusive and reflective approach with stakeholders rather than a more autonomous reactionary stance.

3.2 Barrier mitigation in England

Adaptive management shows some success for barrier mitigation, but not always.

3.2.1 River Browney

Radio telemetry of upstream migrating adult brown trout on the River Browney (a tributary of the River Wear in North East England), showed that a flow-gauging station (pool-and-weir) at Burn Hall (lat.: 54.740900; long.: -1.5995736 (**Figure 2**)) formed a velocity and behavioral barrier to fish migration and dispersal, especially under low flow conditions (Tummers *et al*., 2016a). Following earlier barrier management further up the sub catchment on the River Deerness (a tributary of the Browney), the Burn Hall barrier was retrofitted by the EA with a bottom-baffle technical fishway. However, further barriers located downstream of the confluence, on the Wear, have so far not been mitigated. It is therefore questionable how effective such barrier management is for this catchment in restoring freshwater fish communities, given the illogical order of managing barriers located further up the catchment prior to those further down the system.

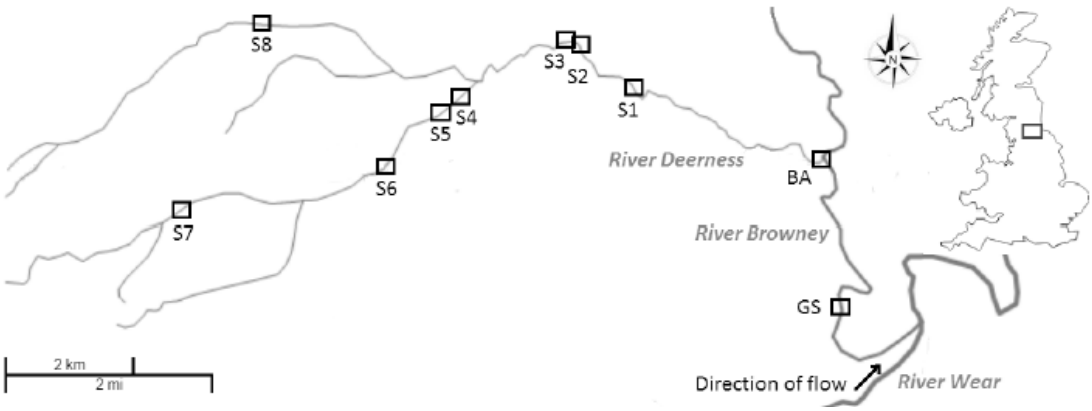

Figure 2. Location of Burn Hall flow-gauging station (GS) located on the Browney, and an additional nine structures mitigated prior to GS, within the River Wear catchment and, inset, location within Britain.

3.2.2 River Derwent

Further south, on the River Derwent, a 20 m wide Crump weir (built with the purpose of gauging river discharge) at Buttercrambe (lat.: 54.0181; long.: -0.8853; **Figure 3**) has been shown to impede upstream migration for river lamprey. Because the catchment is designated a Natura 2000 Special Area of Conservation (SAC), for which river lamprey are a listed feature, a bottom-baffle fishway was installed, which proved to be less effective in passing adult river lamprey upstream than over the weir face directly (Tummers *et al*., 2016b). Modification of the fishway by adding studded modular plastic

tiles adjacent to the fishway wall was successful in reducing fragmentation. To facilitate upstream passage over the weir further, the same tiles were used directly on the weir face, which resulted in a threefold increase in the number of ascents compared to a neighbouring control route (Tummers *et al*., in prep.). An adaptive management approach, based on in situ quantitative experiments, at this site has thus proven effective in increasing longitudinal connectivity within the catchment.

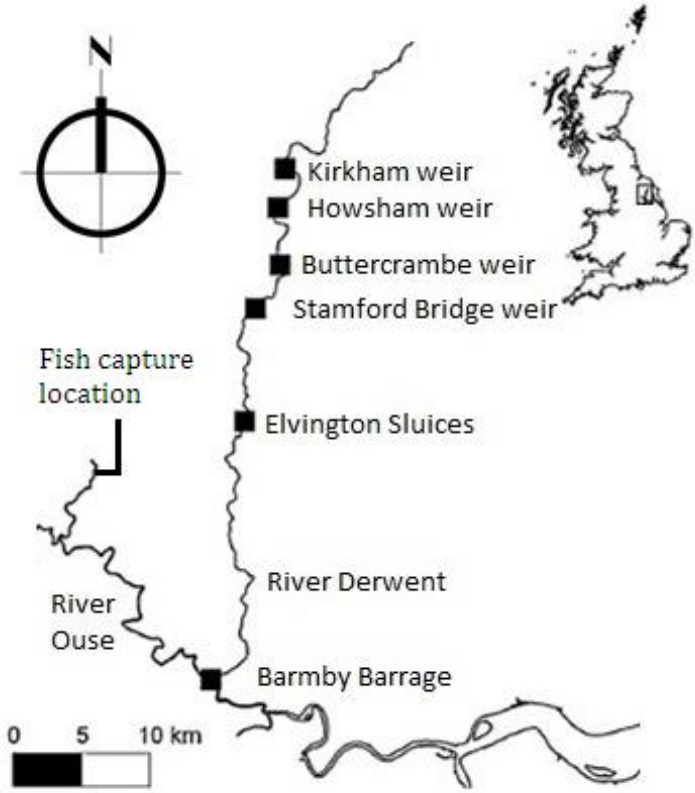

Figure 3. Location of Buttercrambe weir relative to other obstructions on the lower Derwent and, inset, location within Britain.

3.3 Vilholt Hydrodam removal, Denmark

Managing human emotions makes for a lengthy removal process.

The River Gudenaa is one of the largest rivers in Denmark, running for 150 km before entering Randers Fjord (**Figure 4**). In 1865, a landowner established the Vilholt hydrodam in order to power a woodcutting facility. In 1912, a concrete dam replaced the original wooden one. One turbine was operational from 1865 to 2007. Lake Mossø is located approximately 6 km downstream of the dam, and is home to a valuable population of lake-dwelling brown trout, which use the lake as feeding grounds, but need to spawn in the river. The dam blocked the spawning migration, and the lake trout were confined to spawning in the downstream area or in small tributaries.

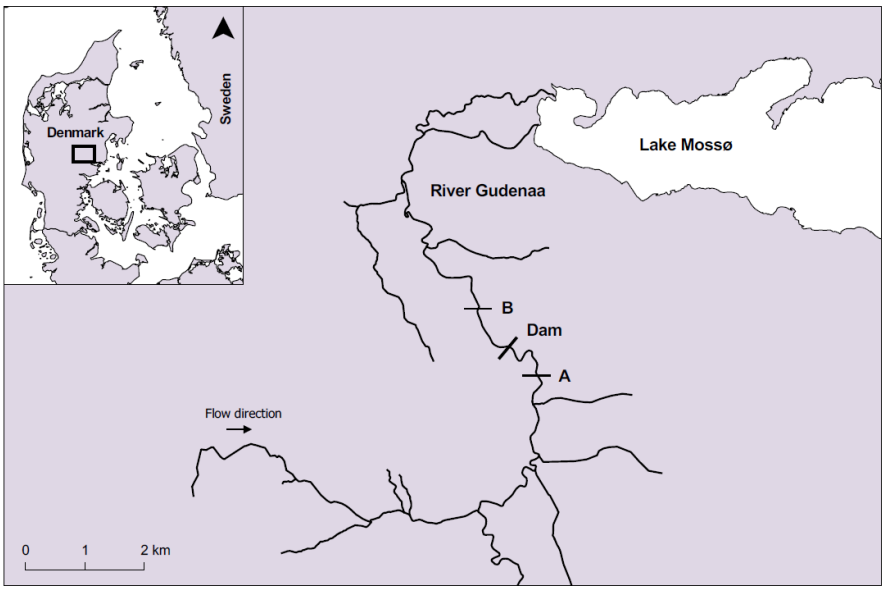

Figure 4. The Vilholt hydrodam was located in river Gudenaa, approximately 6 km from Lake Mossø. Surveys were performed at sites A and B. NB: Figure taken from Birnie-Gauvin *et al*., 2017c.

Discussions about the need to restore river connectivity by removing the Vilholt dam had been ongoing between local authorities (Vejle County and Horsens Municipality), the National Forest, Nature Agency (NA) and stakeholders since 1987. In 1991, the NA purchased the concession (right to use the water) from the landowner. The dam was finally removed in 2008, after nearly two decades of debate. Why did it take so long?

Timeline:

- 1987 Monitoring of fish populations upstream and downstream of Vilholt Dam began
- 1991 Ministry of Environment (NA) purchase the concession in order to remove the barrier
- 2003 Aarhus University carries out a detailed habitat assessment
- 2004 Negotiations with landowners, local authorities and interest groups initiated
- 2006 Final project description drafted
- 2007 Power production halted and turbine stopped
- 2008 Land claim sanctioned in court
- 2008 Project initiated: Vilholt dam is removed
- 2009 Project finished

The reasons why it took 21 years to remove this small and largely unused dam are numerous. The project was first halted due to resistance by landowners, who wished to maintain the status quo (i.e., enjoy the view of the dam, the sound of the water, the ponded zone etc.). Most of the resistance came from a single landowner.

In 2003, after the implementation of the European WFD there was a new political focus on river connectivity. The landowner resistance was still ongoing, and another factor came into play: a tape recording of the rare pond bat (*Myotis dasycneme*). A local nature conservation group raised doubts about the potential effects of the pond removal on the rare bat. The results of an inquiry by an international bat expert were inconclusive, but the group demanded a delay in the removal. At the same time, locals with strong cultural interests were concerned about the loss of historic assets that might result from the removal. Then finally, in 2004, the NA called for a discussion of the project with all stakeholders in a failed attempt to reach consensus.

The final project was drafted in 2006 following the death of the most resistant person in the landowner stakeholder group. After further discussion with cultural interest groups and others, it was agreed that removal was the most viable option to reinstate connectivity for fish. Information about the cultural aspect of the dam and its surroundings were made available to the public through pamphlets and signs. As part of the project, in an attempt to maintain habitat for the pond bat (**Figure 5**), and to compensate for the loss of lentic habitat, two ponds and one oxbow wetland were established.

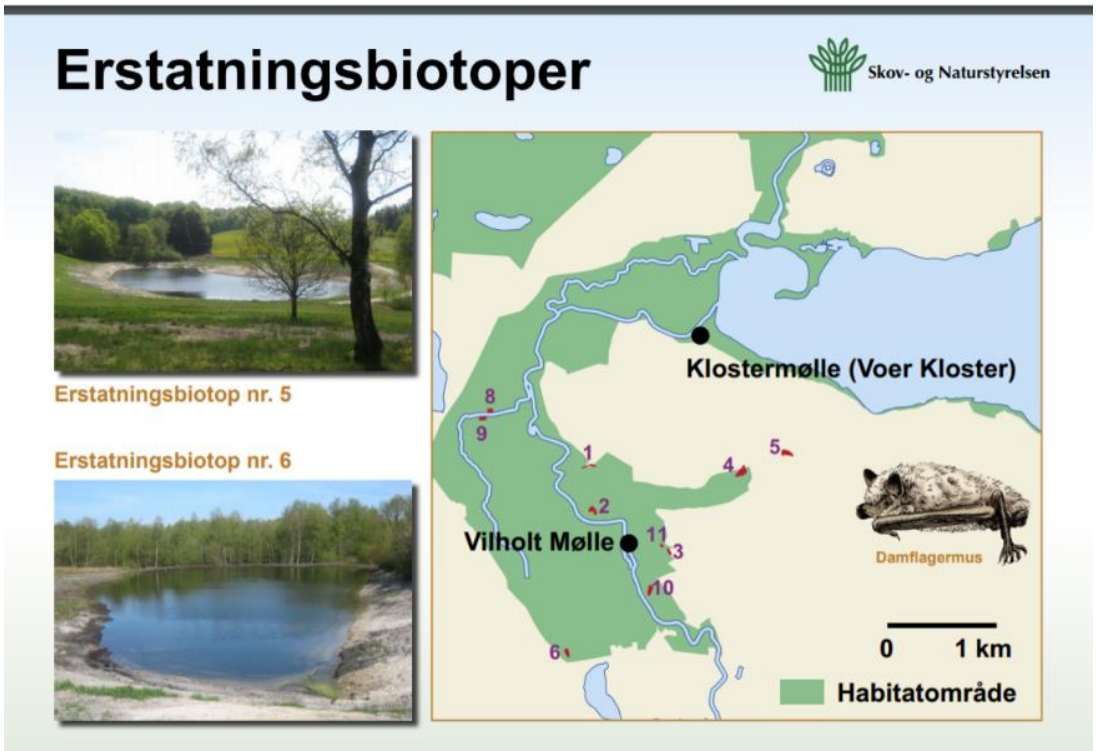

Figure 5. A view of the two compensatory ponds established to accommodate the foraging of the pond bat (*Myotis dasycneme*).

In the 10 years since the project was finalized, all local and non-local stakeholders have been happy with the outcome and no conflicts remain. The results of the removal on the trout population have been tremendously positive (Birnie-Gauvin *et al*. 2017c; **Figure 6**). The cost of the whole project was 6.1 million DKK (820,000 EUROS).

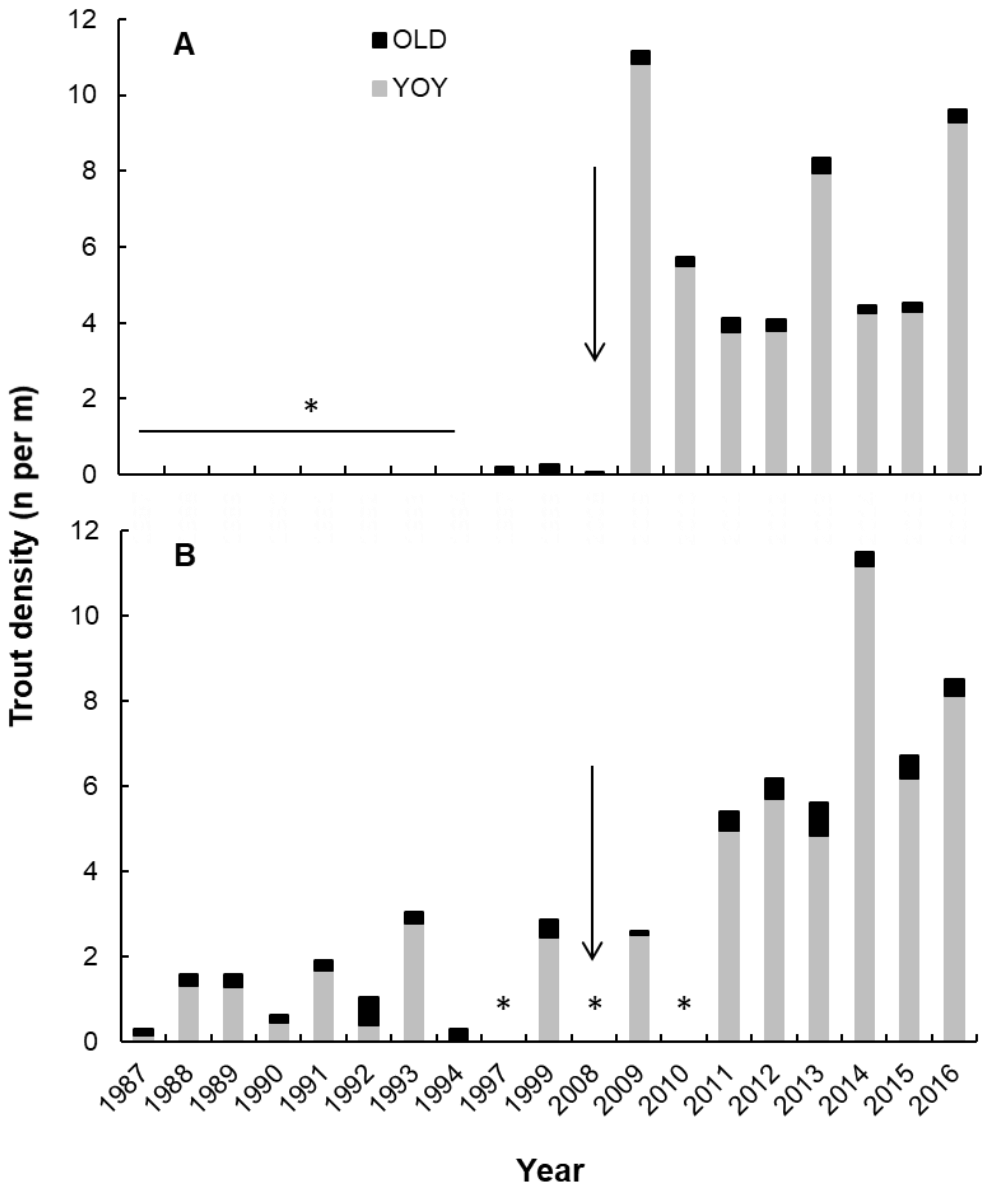

Figure 6. Brown trout (*Salmo trutta*) density upstream (A) and downstream (B) of the Vilholt dam. Downward pointing arrow shows dam removal. Asterisks represent years when no surveys were carried out. NB Figure taken from Birnie-Gauvin *et al*. 2017c.

While the Vilholt removal exemplifies attempted AM, it is clear that the process was too lengthy, and, ideally, an outcome should have been reached years before. If a participatory approach, involving all interests in the decision, had been adopted from the start, there may well have been a speedier solution. We can however see that AM elements played a role in reconciling different interests, and that a single individual can have a large impact on decisions.

3.4 Belmontas Dam, Lithuania

Poor dam management highlights how adaptive management could have saved the day

The River Vilnia (commonly known as Vilnelė) is a tributary of the River Neris, the second largest river in Lithuania. The original Belmontas dam, also known as Pučkoriai dam (**Figure 7**, #1), was built on the River Vilnelė more than 150 years ago, approximately 7.5 km from its exit into the River Neris. The current dam has a fish ladder (efficiency unknown). Approximately 4 km upstream of the Belmontas dam, is a second dam, the Rokantiškių (**Figure 7**, #2). The Rokantiškė dam (originally built in 1934), was transformed in 2004 when turbines to convert it into a hydropower plant were installed. A fish ladder is also present at this dam (efficiency unknown), and the dam is in extremely poor shape. A third dam, the Margiai (**Figure 7**, #3), was built in the upper reaches of the river. This dam is considered less important in terms of salmonids like Atlantic salmon and sea trout as there are almost no spawning grounds in this area (possibly due to the presence of the dams). This means that currently, any fish migrating from above the Margiai dam would have to pass at least one hydropower plant, and go through two fish ladders. Nonetheless, Baltic salmon can migrate from 400 to 500 km into River Vilnelė from the Baltic.

Figure 7. River Vilnelė, a tributary to River Neris, is located in Eastern Lithuania, where it has three dams: 1) the Belmontas dam, 2) the Rokantiškių dam, and 3) the Margiu dam.

A privately owned leisure complex, renowned in Vilnius, comprising restaurants, conference halls, hotels, and a park for outdoor activities sits near the Belmontas dam. The dam has served as a popular site for wedding photography, (the falling water is often associated with waterfalls), and is visited by thousands of tourists on an annual basis, serving as an important attraction and income for Vilnius.

The dam was in very poor condition, but, although this was known for a long time, no action was taken to improve the situation; then, at the end of 2016 just before Christmas the Belmontas dam collapsed. The realization that the dam had no official owner only came after the collapse. In such cases, the law states that the responsibility for taking action falls to the municipality where the dam is located (Vilnius). Following the collapse of the dam, the Ministry of Environment advocated for complete removal of the dam, while a prominent local stakeholder advocated for its restoration. Given the prior lack of care and maintenance (even with the knowledge of the dam's poor condition), such active pro-dam advocacy was not anticipated.

The collapse caused water levels to drop critically, with no water at all entering the fish ladder (**Figure 8**), migration of salmon and trout upstream became impossible. The collapse also caused a large amount of mud to flush downstream covering spawning beds below the dam, essentially reducing any chance of successful salmonid spawning to zero.

Figure 8. Belmontas dam before (A) and after (B) the collapse; the fish ladder before (C) and after (D) the collapse; the "waterfalls", known to attract tourists, before (E) and after (F) the collapse. View from upstream (G) and aerial view (H) of the dam after collapse.

In late spring/early summer of 2017, the Ministry of the Environment made a final decision to remove the dam. Before this decision was taken, there were meetings, consultations and discussions between the Ministry of the Environment, the State service for protected areas under the Ministry of Environment (SSPA), Verkiai Regional Park, environmental NGOs, the municipality of Vilnius and local business owners. The SSPA and Verkiai regional park were of the opinion that the dam should be re-built, because it was deemed valuable from a cultural and recreational point of view. Dam reconstruction was favoured by the head of the Laboratory of Ecology and Physiology of Hydrobionts at the Nature Research Centre in Lithuania, and was further supported by local business owners who believed the dam attracted tourism.

It is important to note that, at the time, there was no active public outreach regarding the benefits and drawbacks of dams and their removal. As a result, two major diverging public discourses developed. Grounded within environmental arguments, such as improvements in fish migration, the environmental NGOs, backed by a few scientists and anglers, supported the removal of the dam. Nine NGOs collaborated to start a petition in favour of dam removal that gained 1033 signatures. Meanwhile, the opposition highlighted the fact that the presence of the dam has caused the formation of a new ecosystem, which would be harmed by its removal. The employees of the leisure complex also started a petition to save the dam and collected 3660 signatures.

The Ministry of the Environment decided to remove the dam despite opposition. Financial support to remove the dam was settled with the European Union. However in late spring 2017, the head of Department of Cultural Heritage, under the ministry of Culture announced, “actions were taken” and enlisted the dam as cultural heritage. All demolition plans were cancelled and the reconstruction works began in order to improve the critical state of the collapsed dam. In November 2017, the Ministry of Environment claimed that dam reconstruction works were illegal and carried out without permits. The construction works continued nonetheless. By the summer of 2018, dam reconstruction, funded by the municipality of Vilnius was nearly complete. There are rumours that, though the old dam was regarded as cultural heritage, the new one was built higher than the old one and does not resemble it. The rumours of a height change are backed up by the fact that those advocating maintenance of the dam are diverting water from the fish pass to the dam. Meanwhile, activists keep removing the diverting structures from the fish pass, to ensure that there is enough water for fish to migrate.

This example highlights how AM could have prevented this process from occurring through:
1) performing proper assessments and monitoring of the surrounding habitat and fish populations, and in performing proper maintenance of the dam (the owner of which would therefore have been identified); or 2) having done a proper evaluation of the costs and benefits of reconstruction, considering all stakeholders, including environmental agencies (which were not properly consulted in this case).

3.5 Caleao Dam, Spain

New dam: from proposal to acceptance to renouncement.

The River Nalon is located in the central part of the region of Asturias (Northern Spain). The area is in economic decline due to the closure of coal mines and the abandonment of agriculture/husbandry activities after the country’s entrance in the EU common economic space in the 1980s. The Nalon valley shelters the most famous mining zone of the region, especially in the middle part of the river. This part is still much degraded. The Cantabric Hydrographic Confederation has carried out several

restoration programs in the river valley and main tributaries. The water quality has improved in the middle zone in the last decade but is still poor downstream, where the river hosts the majority of exotic fish recorded in the region. Upstream, head tributaries compose the UNESCO Biosphere Reserve and Natural Park of Redes.

There are seven dams in the river system, built primarily in the 1960s and 1970s, with diverse uses: water supply, hydro electrical power, control of flood risks, as well as recreational activities (fishing, canoeing). There are fishways in only two of the dams, with unknown efficiency.

A new upstream dam project (the Caleao Dam) has been discussed since 1992 for water and energy supply, as well as for compensatory flows to maintain biodiversity. Construction, it was argued, would enhance water quality to a level that is thought to be adequate for salmonids downstream (however, no matter what the water quality upstream, it is unlikely that many individual salmonids will migrate past the seven dams, especially given that only two of them have fish passes). The dam project, jointly promoted by the Regional Government of Asturias and CADASA (Asturias Water Consortium), was initially submitted in 2001 and was rejected for inclusion in the Spanish Hydrological Plan. In 2004, the project was proposed again, and a public debate was opened that year.

A civil platform was created in 2006 for defending the Natural Park of Redes (a UNESCO Biosphere Reserve since 2001) and the valley of Caleao. Groups camped by the river on the 24th to 26th of September 2006, to protest against the plans. At least two NGOs (part of the platform) submitted initial complaints against the project draft, but the complaints were rebutted. In 2007 and 2008, the platform against the plans and for the protection of the Biosphere Reserve were held again, with no reports of interference from the regional government.

Construction plans continued and were presented publicly. The written plans were deposited in the headquarters of the Regional Government for public consultation, complaints from any private party, public institution, NGO, or individual, were possible until 30th of June 2015. The Spanish National 2015-2021 Hydrological Plan studied the complaints and countered all of them, passing the plans to the next phase, meaning that construction of the Caleao Dam could be foreseen within the next few years.

The dam project has been contested by ecological and conservation associations because of the way it will affect the Natural Park of Redes (Natura 2000, LIC, ZEPA, Biosphere Reserve) and several protected species therein. On the 11th of May 2018, the Asturias Parliament approved a “resolution” for the Asturias Regional Government to renounce the dam project in the Plan of Water Supply that will be presented by October 2018. The proposition was presented by the Izquierda Unida party, because of a new Agreement between CADASA (Asturias Water Consortium) and the multinational steel and mining company Arcelor-Mittal that has investments and interests in Asturias. The new agreement stipulates that while the Caleao Dam project has been abandoned, new plans to exploit the River Narcea (a tributary to the Nalon River) are on the horizon.

This Caleao Dam decision-making process is a good example of stakeholder engagement going from poor to good (i.e., the early phases of the project did a poor job of including ecological and conservation associations, but the later phases improved their engagement). While this case study exemplifies a good outcome (i.e., the abandonment of the construction), it also illustrates that it will come at a cost: exploitation of another part of the system (River Narcea). This new agreement will probably lead to a similar process, including protests against the exploitation, but is unlikely to follow an adaptive management process because it originated as a compromise to the abandonment of the Caleao Dam.

4 BEST PRACTICE & CONCLUSION

4.1 Lessons learned

Section 3 presented specific case studies of barrier management highlighting situations where AM was successful, and others when it was not. Using these examples, we can extract and put into practice best practice measures that will help make for more successful AM in the future (**Figure 9**).

1. Before AM can be implemented, AM practitioners need to determine whether:
    a. There is substantial ecological value to be gained;
    b. There is a risk of a long lasting conflict;
    c. There are a number of stakeholders that can be identified;
    d. There are opportunities for learning, reconsiderations and alternative management options;
    e. There is sufficient funding.
2. To address the issues at hand AM practitioners need to perform appropriate assessments to determine the current state of rivers in relevant temporal and spatial scales.
    a. Proper biological assessments (e.g., fish, invertebrates) both upstream and downstream of barriers: undertaken on multiple occasions prior to making decisions.
    b. Proper habitat assessments (e.g., substrate, flow) both upstream and downstream of the barriers.
    c. Assessments should be representative of the whole system, and not just locations where barriers are absent. Ideally, assessments should be performed upstream and downstream of *every* barrier in a system. This would give the most complete assessment.
    d. Assessments should be performed before the AM process begins to avoid delays.
3. AM practitioners must identify all stakeholders involved, not just a subgroup. Furthermore:
    a. Agreement should be reached to ensure that a single stakeholder is not able to prevent the consensus.
    b. Overrepresentation of a stakeholder subgroup should not influence the decision because they are visually more numerous; often, the resources that cannot be seen lose (e.g., an environmental group arguing for the protection of fish will often lose against 15 local business owners simply because the fish cannot be seen, but the businesses can).
4. AM practitioners need to be familiar with the bureaucracy involved in mitigation and restoration practices. Simultaneously, the agencies involved in this bureaucracy should ensure relatively fast processing to avoid delays in implementation.

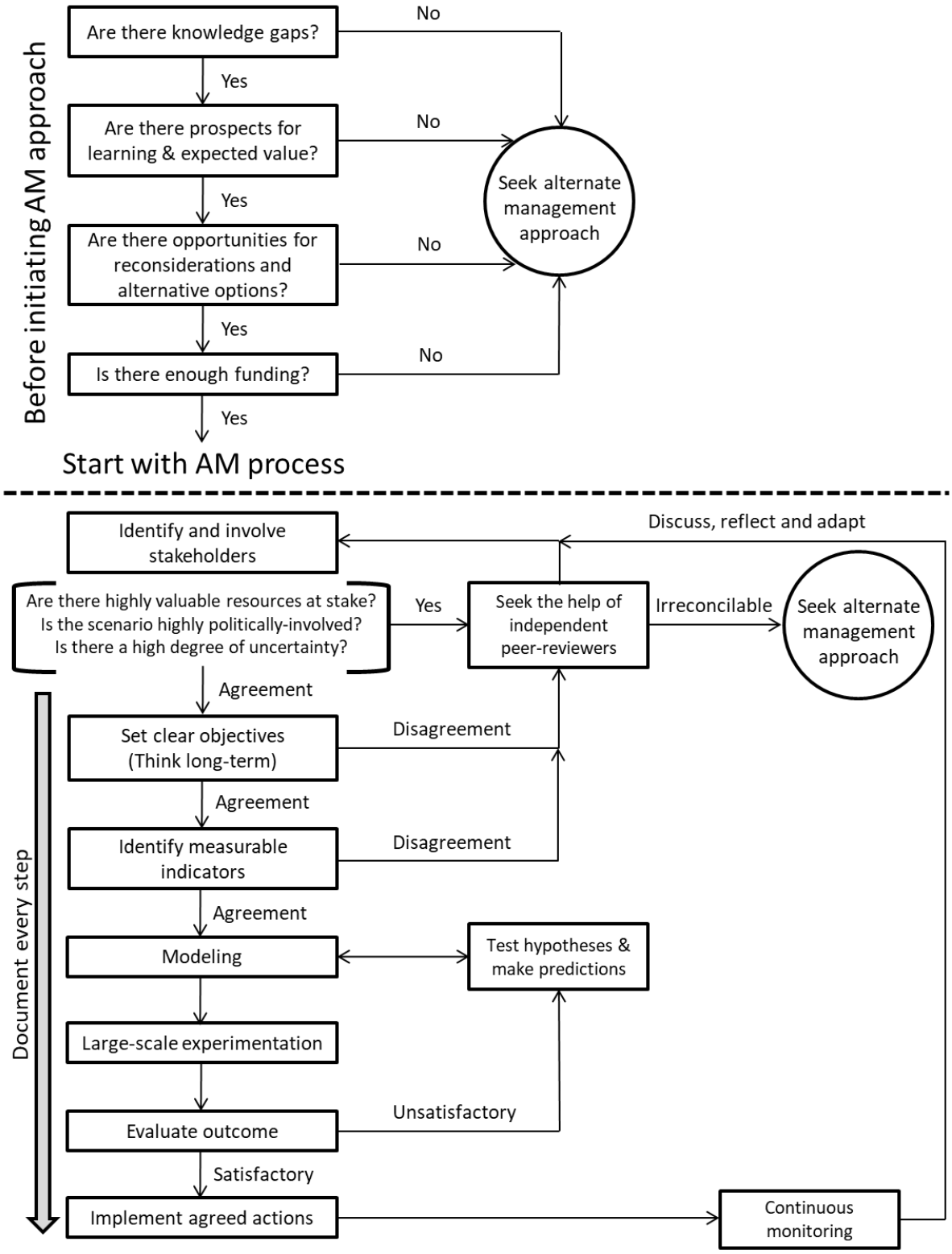

Figure 9. Adaptive Management process (Birnie-Gauvin *et al*. 2017b).

In addition to these best practice advice, there are many instances when AM should not be implemented, some of which were highlighted in the examples from Section 3. **Table 1** below (taken

from Birnie-Gauvin *et al*. (2017b)), should help practitioners identify instances in which AM is not the correct approach.

Table 1. When not to use adaptive management

Instances when NOT to use adaptive management
To delay a process.
When there are no knowledge gaps.
When no clear objectives have been set.
When funding is a problem.
When opportunities for improvement lack.
When later reconsiderations are not an option.
When alternatives are limited.
When mistakes are irreversible.
When no measurable indicators are available.
Irreconcilable stakeholders

An important aspect to consider when practicing AM in the context of barriers is to clearly state the use of AM in the terminology of reports and/or peer-reviewed publications. Currently, the lack of mentions of "adaptive management" in documentation makes it difficult for other practitioners to learn lessons from already existing examples of both successes and failures of using AM in this particular context.

4.2 Conclusion

There is a high and increasing demand for barrier management in Europe, and the fate of numerous dams must be decided in the coming years. To avoid poor management decisions and the consequent long-lasting conflicts, sound management practice and decision making processes are necessary. The concept of adaptive management may not always suit these needs, but there is obviously a large potential benefit in applying the central elements in barrier management. At present, we urgently need research in, and documentation of, the outcomes of past and ongoing barrier removal/mitigation projects in the EU.

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