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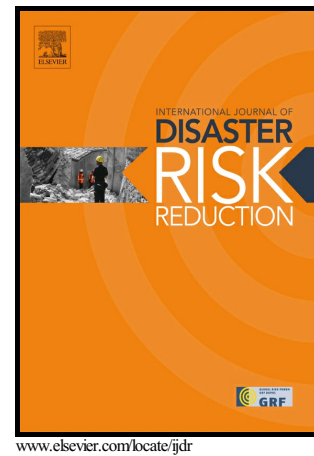
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Ecosystem-based solutions for disaster risk reduction: lessons from European applications of ecosystem-based adaptation measures

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Abstract

Disaster risk reduction (DRR) and climate change adaptation are connected through a common goal: reducing the impacts of extreme events and increasing resilience to disasters, particularly among vulnerable populations. By coordinating adaptation and disaster risk management policies, multiple benefits can be achieved. Ecosystem-based adaptation (EbA) offers a cost-effective adaptation and DRR at different scales and under multiple scenarios. EbA uses natural or managed ecosystem processes to increase resilience and adaptation to climate change. EbA delivers other benefits, including mitigating greenhouse gases, and improving biodiversity, water and air quality. These co-benefits can be the primary driver for implementation and reflect related policy objectives. EbA are also associated with different land use or habitat types (e.g. agriculture, forestry, coastal, urban, or freshwater ecosystems).

This paper considers the lessons learnt from implementing EbA across a range of land uses. However, implementation frequently applies multiple measures across land uses and at varying scales. The evidence indicates that adaptation and DRR are achievable cost-effectively whilst providing important co-benefits. Demonstrating these co-benefits ensures both stakeholder support and funding opportunities. Further, the mainstreaming of nature-based solutions across policy areas linked to different co-benefits both increases the acceptability of EbA and also opens up multiple funding sources. Key to the success of EbA is the involvement of stakeholders throughout the implementation process; this can include demonstrating private benefits and utilising trusted intermediaries. However, gaps often remain in our knowledge of the biophysical and economic benefits, or negative impacts, of EbA indicating that research and monitoring remain a priority.

Keywords: Disaster Risk Management; Ecosystem-based Approaches; Climate Adaptation; Ecosystem Services

1 Introduction

The year 2015 marked significant progress in the international frameworks for sustainable development, climate change and disaster risk reduction and management. The 2030 Agenda for Sustainable Development and its Sustainable Development Goals recognize the need to enhance the resilience of people and the planet to disasters and to the impacts of climate change (United Nations, 2015a). The Sendai Framework for Disaster Risk Reduction (United Nations, 2015b) strives to mobilise action of all actors for reducing the impacts of disasters at all levels. Finally, in the Paris Agreement on Climate Change for the first time governments adopted a global adaptation target to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change (United Nations, 2015c, Article 7).

The 2016 Global Risk Report (WEF, 2016) identifies the risk of failure of climate change mitigation and adaptation as the highest risk in terms of impact, whereas the risk of extreme weather events ranks second in terms of risk of likelihood (see Figure 1).

There is thus a sense of urgency to step up efforts to combat climate change and its impacts, enhance resilience and the ability of people and ecosystems to withstand disasters – with climate change expected to further exacerbate weather related extremes.

Disaster risk reduction (DRR) and climate change adaptation (CCA) are connected through the common goal of reducing the impacts of extreme events and increasing resilience to disasters, particularly among vulnerable populations. Doswald and Estrella (2015) note that due their close linkages there are growing calls for the integration of CCA and DRR policy. This is well recognised in EU policies and strategies, as signalled by the recent developments in these fields. Over the last decade, the policy framework for CCA and DRR at the EU level has evolved significantly, with increasing synergies between the two policy spheres, and more systematic attentions payed to the potential role of nature based solutions. The 2013 EU strategy on adaptation to climate change (European Commission, 2013) calls for the implementation of adaptation policies in synergy and full coordination with disaster risk reduction. It also highlights the multiple benefits of ecosystem-based approaches, and their contribution to achieving its strategy objective of a climate-resilient Europe – including disaster risk management and reduction. The EU Action Plan on the Sendai Framework for Disaster risk Reduction (European Commission, 2016), which provides a coherent agenda for enhancing risk prevention, building the resilience of societies and developing risk-proofed investments through different EU policies, flood risk management, water and biodiversity protection. In addition, a range of sectorial policies including the Floods Directive, the Biodiversity Strategy and the EU Green Infrastructure Strategy recognises the need for an integrated approach to risk management and therefore contributes directly or indirectly to strengthening the CCA and DRR agendas. A more detailed description of relevant EU policies and their implications for the development and deployment of EbA and Eco-DRR measures is contained in Faivre et al. (this issue). This includes the concept of nature-based solutions (NBS) which is a key element of the EU's Research and Innovation policy (European Commission, no date). NBS are a good example of horizontal and cross-sectoral approaches that promote a more systemic view to harness multiple opportunities and address often complex and interlinked challenges.

Ecosystem based disaster risk reduction (Eco-DRR) can be defined as “the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development” (Estrella and Saalismaa, 2013).

Ecosystem-based Adaptation (EbA) is defined as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change" (CBD, 2009).

Thus, both EbA and Eco-DRR enable people and ecosystems to adapt to the impacts of climate change and/or disasters through the sustainable management, conservation and restoration of ecosystems to provide ecosystem goods and services. The two approaches have in common that they can generate multiple benefits: climate change mitigation and adaptation, disaster risk reduction, biodiversity protection, food security, and job creation, to name just a few (CBD, 2016). Healthy ecosystems can also reduce socioeconomic vulnerability by providing essential goods and services to people, such as supporting income generation and protecting human health (EEA, 2013).

However, there are also differences in scope and approach between the two, that need to be understood for effective adoption of ecosystem based solutions. The most obvious difference is that, while EbA addresses climate-related natural hazards, Eco-DRR also deals with other types of disasters, such as earthquakes (Doswald and Estrella, 2015). A more subtle difference, that will impact the type of approach and measure adopted, relates to the timeframe of the underlying analysis (Doswald and Estrella, 2015). Planning for effective EbA requires taking into account long term changes in frequency and intensity, as well as future potential impacts from climate change, including slow-onset events. On the other hand, Eco-DRR typically deals with current risks and disasters (Mitchell and Van Aalst, 2008). Figure 2 illustrates the linkages between climate adaptation and DRR.

At their intersection, EbA and Eco-DRR can be implemented in a variety of sectors to address multiple hazards – while also generating additional ecosystem service benefits (CBD, 2016). This range of potential ecosystem service co-benefits means that EbA measures can contribute to both climate adaptation, and be of interest to a variety of stakeholders (see Figure 3). For instance, the protection or restoration of wetlands and floodplains can buffer against floods, including flashfloods (Doswald and Osti, 2011). Similarly, restoring coastal wetlands, mangroves and coral reefs could reduce the vulnerability to and impact of storm surges (Hettiarachchi et al., 2013). Green infrastructure and spaces, roof gardens, tree-lining in urban environments help reduce the impacts of heat waves, while also enhancing water retention (Strosser et al., 2015).

Different EbA can be categorised reflecting land use or land cover, groups of measures and specific measures (see section 2 for a fuller description) together with the hazards these might address. At the level of individual measures it might be possible to make a distinction between EbA and Eco-DRR measures. However, we would argue that this distinction becomes artificial when the approaches are considered in their entirety. Implementing EbA or Eco-DRR often means applying multiple measures in a coordinated manner, each providing several adaptation or DRR responses. The cumulative effect of the individual measures and the spatial scales that are covered, thus leads to a blurring of the distinction between what constitutes EbA and what Eco-DRR.

The protection and restoration of resilient ecosystems are among the most cost effective means of limiting the scale and negative consequences of disasters and climate change, in particular when considering all the co-benefits of the measures beyond enhancing resilience against hazards (Naumann et al., 2011). The objective of this paper is to present the

evidence of the effectiveness and efficiency of EbA in different sectors and at different scales in Europe. Building on the evidence gathered by analyzing 122 case studies, lessons learned will be distilled, with a specific focus on how EbA can simultaneously address the challenge of DRR.

The remainder of the paper is organized as follows. Section 2 outlines the methods and data sources used in our review. Section 3 presents the results of our review of case studies. This focuses on the evidence of effectiveness presented by case study sources in terms of both the biophysical and economic impacts of implementing ecosystem-based measures. We also consider the factors that either contributed to or limited the successful implementation of measures. Given the large number of case studies identified we draw general messages with illustrations from selected case studies. We conclude the paper by identifying the policy implications of the case study evidence review.

2 Methods

2.1 Review of evidence

The aim of our review was to assess the evidence from applications of ecosystem-based adaptation in Europe. It was restricted to publically available sources that might typically be used by policymakers and other decision makers. As such it was not intended to be a review of the peer-reviewed literature or an evaluation of the 'state of the art'. Our purpose was not to assess the effectiveness of particular measures or applications, rather to determine the extent to which case study sources provide evidence of effectiveness, particularly in terms of their response to climate hazards and their cost-effectiveness. We were also interested in identifying the key factors that lead to successful implementation, or the barriers that might limit a successful implementation.

Given the scope of our assessment we focused on a small number of key information sources that are accessible to decision makers across Europe. Our primary source was the European Environment Agency's Climate-ADAPT web platform (Climate-ADAPT, no date). In line with the criteria adopted by Climate-ADAPT we excluded case studies completed prior to 2005 (some long term applications of EbA started before this point). A total of 125 case studies were identified. Of this, 24 relevant case studies were in Climate-ADAPT and a further 92 on the Natural Water Retention Measures site (NWRM, 2015); these formed our initial database of case studies. Further searches were undertaken on a number of sites with following results:

- ADAM Digital Compendium (ADAM, 2009) - no studies after 2005, this was out of our determined scope.
- WeADAPT (no date) - 8 relevant studies 3 of which included in the assessment.
- LIFE project database (LIFE, no date) - no 'adaptation' results funded before 2014 (note a number of previous LIFE funded projects are however included in the NWRM case study results, suggesting that other drivers were important).
- OPPLA case study finder (Oppla, no date a) - 7 results, of these 2 related to implementation of EbA measures but were rejected as no quantification (implementation and/or impacts) was provided.
- OPPLA Nature-based Solutions Case Studies (Oppla, no date b) – 3 results.
- CORDIS project database (CORDIS, no date) - three out of 34 projects potentially related to EbA. Only one result (Bottom-up Climate Adaptation Strategies towards a Sustainable Europe, BASE FP7) provided case studies of EbA implementation, 2 case studies included in assessment (BASE, no date).

All searches were completed prior to 1 September 2016 to allow time for our analysis, but we note that Climate-ADAPT is a live database and will have been added to since that time. From a total of 125 case studies, we refer to 52 in the following results section, these 52 are referenced in the Appendix, the full list can be obtained on request from the authors.

The EbA measures identified in our assessment can be categorised across a number of land use or land cover categories (as shown in Table 1). Within each category, broad measures can be identified each with a larger number of specific measures. Arguably, the 'water management' category does not reflect a distinct land use or land cover in the same way as other categories as these measures will often be applied in the context of those other categories (e.g. rivers flowing through urban areas). Figure 4 illustrates the number of applications of EbA measures across the case studies grouped by categories, notably these total 215 across the 125 case studies illustrating the application of multiple measures. The figure also indicates the dominance of water management applications, arguably this reflects the focus of the NWRM project which was tasked with identifying case studies across all EU member states. There were a relatively low number of coastal case studies, this possibly reflects the difficulty in categorising coastal projects as EbA due to frequent combination of grey and green engineering elements. Some coastal measures such as beach nourishment are controversial and may rely on ecologically damaging dredging operations, so may not have been classified as EbA in the data sources.

As noted above, the typical implementation of multiple EbA measures at wide spatial scales makes the distinction between adaptation and DRR difficult. Although some of the case studies in our review may not fully provide an Eco-DRR role, we retain them in the results as they may nevertheless provide useful lessons regarding the evidence provided and successful implementation. 'Success and limiting factors' is a section used in the Climate-ADAPT database's description of case studies, and describes factors beyond biophysical or economic impact that contributed to, or limited, the successful implementation of the measures. The NWRM case study reporting template offers similar information in terms of 'lessons, risks, implications...' which includes 'success factors' and 'barriers'. We do not impose any classification or threshold on success or limiting factors, instead these are reported as per the evidence sources. For other evidence sources we have classified success and limiting factors where reported in a manner consistent with Climate-ADAPT. The case studies also refer to existing applications of measures so address the more proximate timescales relevant to DRR.

3 Results

3.1 Biophysical impacts

In this section we outline the results of our review with respect to biophysical impacts. In particular we focus on the nature of the evidence presented by case studies and the potential to draw generalizable conclusions about EbA implementation. Our discussion considers the differing scales of implementation and the different measures of impact being used. We then illustrate the difficulty of comparing combinations of scale and impact metric with respect to three broad EbA measures: river restoration, wetland restoration and groundwater management.

A key lesson from the case studies that were identified from our information sources is that measures have been applied across a wide range of scales. These may not always be

appropriate for determining the effectiveness of measures for adaptation or DRR. This makes comparison between case studies difficult as the catchment level results are likely to more closely reflect the scale of impact relevant to adaptation, whereas extrapolating from field level is far less robust. However, those case studies might still be instructive as they provide important lessons in terms of potential effectiveness or in encouraging implementation and uptake.

For example, agriculture case studies vary in scale of application from plot or field level (0.03 ha, combining no till and green cover, *Cover Crops and No-Tillage in an Olive Grove*) to catchment scale (6000m of flood breaking hedgerows covering an area of 35000 ha, *Flood breaking hedgerows in Southern France*). Urban case studies also display a large variation in scale from city-wide programmes of multiple measures (e.g. *Stuttgart: combating the heat island effect and poor air quality with green ventilation corridors*) to small-scale implementation of individual measures (e.g. 0.015ha of raingardens within a 0.55ha 'catchment', *Rain gardens for the Day Brook*).

Furthermore the actual management or implementation of measures may only reflect a relatively small area of a much larger site. For example the *Multi-purpose water management development along the Körösér* study has a large catchment area (48,100 ha) but only a small area of management change (5 ha) for retention ponds. Lake restoration varied considerably in scale from 154 to 12,285 ha (*Tamera water retention landscape* and *Wetland management on the Burgas lakes* respectively), although for the latter the restoration work took place in an area of 4 ha. Similarly, floodplain restoration has been applied over a very wide range of scales from 7ha (*Restoring the River Quaggy in London*) to 23,706ha (*Floodplain restoration in the Lonjsko Polje Nature Park*), although it is not clear from the case study sources whether these values relate to the area of the catchment or the area of restored floodplain. Scale may also be expressed in different units reflecting either the area in hectares of the management measures, city or catchment, or the length of features such as rivers or hedgerows.

The biophysical impacts are also measured in a variety of ways including percentage or quantity changes in runoff, peak flow and the volume of water stored. Runoff relates the overall level of surface water flow, whereas peak flow is of more immediate relevance to flood risks. Water storage is related to temporary retention in the landscape which impacts on both peak flow and runoff, as well as contributing to infiltration and ground water recharge. Comparison of the biophysical performance of the case studies is often difficult, for reasons such as differing spatial and temporal scales. For example the 860 million m³ volume of reservoirs and ponds (*Multi-purpose water management development along the Körösér*) measures a different impact to the 120,000 m³ rainwater retention (*Recovery of dried out communities*) as the former includes an element of permanent storage whilst the latter is temporary water retention. Neither are then comparable to the *Rural runoff attenuation in the Belford catchment* study as it reports reduction in daily flow (10,000 m³/day) which is a more appropriate measure for a measure of flowing water.

Where impacts have been quantified (e.g. reduced flow) this may be without reference to a baseline scenario without measures. Two UK forest case studies are to some extent comparable as they employ similar measures (coarse woody debris) within different packages of EbA and report impacts in percentage terms. The combination of coarse woody debris and ponds in the Belford catchment (*Rural runoff attenuation*) achieved a 30%

reduction in flow, where the coarse woody debris and riparian woodland at Pickering (*Slowing the flow*) reduced flow by 11%. However, these runoff reductions are not then translated into the corresponding reductions in flood risk.

The impact of case studies and measures may also be expressed in terms of their outcome with respect to disaster risk. For example, flood reduction might be expressed in terms of reduction in flood return period. In the context of future climate change, severe flooding is expected to become more frequent (EEA, 2013). In DRR or adaptation terms that means that measures are being designed to deal with longer return periods, e.g. 1 in 200 year events rather than 1 in 50 year events. The Sigma Plan (*An integrated plan incorporating flood protection*), for instance, is a large scale Belgian project involving both coastal and water management projects:

- Kruibeke Bazel Rupelmonde (Belgium): a Controlled Flood Area for flood safety and nature protection;
- A transboundary depoldered area for flood protection and nature: Hedwige and Prosper Polders; and
- Floodplain reconnection in the Vallei van de Grote Nete, Belgium (wetland restoration)

The overall Sigma Plan is a long running (since 1977) programme developed in response to a severe storm surge in 1976. It aims to provide protection to both further storm surges and flooding due to rainfall. The overall Sigma Plan is measured in terms of its objectives: to provide protection against 1 in 1000 year flood events by 2050 (compared to 1 in 350 at present or 1 in 70 year with assumed sea level rise). Other case studies of coastal managed realignment provide lower levels of protection ranging from 1 in 30 years (*Titchwell Marsh, UK*) to 1 in 200 years (*Hesketh Out Marsh, UK*), it is not clear whether the different effectiveness of these schemes is related to their relative sizes at 11ha and 160ha respectively.

There were 24 case studies categorised as river restoration, these vary in size from small sites (4.3 ha, *River restoration of the lower Aurino*) and river stretches (0.37 km, *Small scale measures under the 'Waters neighbourhood Days' in Hamburg*) to large programmes (2,236 km² floodplain, within a 9,000 km² river corridor, *Lower Danube Green Corridor*). The scale of the larger projects makes evaluation and comparison difficult as they are likely to consist of multiple smaller schemes using multiple measures and the overall biophysical impacts are often not stated. Where biophysical impacts are quantified they often use different measures (water storage vs. flow reduction) or are over different timescales where conversion to a common measure might not be appropriate. For example flow reduction in m³/second vs. m³/day can be converted to the same units. But this might not be informative with respect to the actual impacts such as flooding vs. low flow maintenance; both are relevant for climate adaptation, but only the former is important for Eco-DRR.

Wetland restoration case studies varied in the scale of application from 0.07 ha (*Constructed wetland in Vidrare*) to 1 million ha (*Small Water Retention Program in Forests*). The biophysical impacts vary across case studies both in scale and the units they are presented in. Where water resources or flood control were the main objectives (*Exmoor Mires peatland restoration*, *Floodplain reconnection in the Vallei van de Grote Nete*, and *Kylmäojankorpi forested wetland*), the results show considerable impacts of the measures:

- *Exmoor Mires peatland restoration*, 32% peak flow reduction (714 ha);

- *Floodplain reconnection in the Vallei van de Grote Nete* 27% runoff reduction (850 ha); and
- *Kylmäojankorpi forested wetland* 38% runoff reduction and 47% peak flow reduction (37.3 ha).

These compare well with one study (*Wetland restoration in Persina*) with a primary objective of biodiversity improvement, which only achieved 5% and 1% reductions in runoff and peak flow respectively. This latter study was considerably larger (4035 ha) compared to between 37 and 850 ha for the studies aimed at flood control and water resources, this may reflect better targeting to measures. In case studies across other categories such as blue infrastructure, water quality was often the primary objective (e.g. *Pollution Treatment on the Glinščica*); however, these measures also provide adaptation responses to water flows, allow increased filtration and sedimentation. This raises the question of whether existing applications have been designed to optimise the adaptation outcome.

Three groundwater management case studies were identified; the primary aim of these is to restore natural infiltration to groundwater in order to respond to water scarcity and drought. These measures are most commonly applied in Mediterranean countries. A distinction can be made between artificial aquifer recharge and natural recharge, in the latter EbA type features (infiltration ponds, soakaways, channels) are used to collect water and allow natural infiltration. The case studies have been applied over relatively small scales from 0.5 ha to 7.56 ha; this suggests that although the measures used can, in other circumstances, contribute to adaptation outcomes such as flood reduction, they are not of sufficient scale in this instance. Despite water scarcity being the main issue in Mediterranean countries, flooding can also be a major problem due to high intensity rainfall events. The biophysical impacts of the case studies are on (or can be readily converted to) a common metric, volume of water retained per day (m^3/day). There is a wide range in the performance across studies, particularly when further converted to volume per ha:

- *Ezousas*, Cyprus: 12,000 m^3/day over 4.61 ha = 2603 $\text{m}^3/\text{ha}/\text{day}$
- *Germasogeia*, Cyprus: 24,000 m^3/day over 0.5 ha = 48,000 $\text{m}^3/\text{ha}/\text{day}$
- *Arenales*, Spain: 7000 m^3/day over 7.56 ha = 926 $\text{m}^3/\text{ha}/\text{day}$

These performance differences may be down to factors such as soil type and structure, rock type and input volumes. The study costs are also very variable ranging from €38,000 for the 'most effective' (*Germasogeia*) to €4.6 million for the 'least effective' (*Arenales*). This is likely to reflect the nature of the works involved: the *Germasogeia* scheme involved maintaining the infiltration capacity of an existing river bed that was being fed by an existing up-stream dam.

3.2 Economic impacts

Assessing the economic efficiency of EbA implementation would ideally use cost-benefit analysis to compare fully enumerated cost and benefits including a wide range of ecosystem service impacts. The next best alternative would be cost-effectiveness analysis which would allow comparisons of biophysical impact per unit of implementation cost. In this section we consider the evidence of economic impact with examples from the agriculture, forestry, urban and river restoration categories. We also present examples of applications where cost-benefit analysis has been attempted.

Much of the evidence on the economic impacts of the EbA measures is restricted to the costs of implementation, as these are readily available at project level. Out of 125 case studies, 107 provided cost information. The variation in both scale of implementation and the biophysical units used to describe impacts means that the cost-effectiveness of applications are hard to evaluate and compare. Monetary evaluations of the benefits are seldom presented, with only 15 case studies providing either quantitative estimates of benefits or noting qualitatively what benefits have arisen. Social impacts are rarely reported, and are typically quantified using proxy measures such as visitor numbers, although positive social outcomes may be inherent in the success of implementation and are implicit in the success factors discussed in the following section. Fourteen case studies did not provide any cost or benefit information.

A variety of economic impact values are also reported across the agriculture category case studies relating to either total costs, or in some cases these are broken down into separate elements such as land acquisition costs, capital cost, and operational and maintenance costs. Some case studies also state the unit costs (e.g. per hectare or per metre) of implementing specific measures, these typically relate the relevant payment rates under the EU's Rural Development Programme. Only one of the agriculture case studies estimates economic benefits (*Agroforestry: agriculture of the future? The case of Montpellier*). The no-tillage field trial study in Austria (*No Tillage Field Trials in lower Austria*) also reports benefits in terms of the cost savings (labour and fuel) from implementing the measures. Consequently, across the case studies it would not be possible to undertake cost-benefit analyses using the available data. Cost-effectiveness assessment would be possible but due to the varying biophysical impact measures reported these would offer limited comparability between studies.

The scale of application of forest case studies ranged between 2.5 ha (*Reforestation in Veneto*) and 12,500 ha (*Preservation of floodplain forests*). However there is no direct relationship between scale and cost, the largest study (*Preservation of floodplain forests*) had an overall budget of €570,000 compared to the €2.9m overall cost for a 49.5 ha site (*Water retention management in the broader area of Ancient Olympia*). These large cost differences reflect the different nature of these case studies, the former is concerned with preserving existing habitats with some new planting, whilst the latter study involved large land purchase costs and extensive preparation work to stabilise slopes ahead of new planting.

The cost estimates for green roofs can vary considerably. Very low costs (~€0.50/m²) are quoted for one case study (*Green roofs in Vienna*), however these seem exceptional low and the source material for that case study suggests a range between €12.50 and €25 per m². The highest costs were up to €90 per m² (*Green roofs in Basel*). The main cost issues are the type of vegetation (extensive vs. intensive) and the costs of strengthening roofs to cope with the additional weight. These costs may be offset by private benefits including reduced cooling and heating costs, the savings being up to €8.5/m² and €24/m² respectively (*Urban green roofs in Helsinki*).

These different scales of river restoration projects described above are also reflected in the costs of the case studies which range from €50,000 (*Climate-adapted management of the Körös-Maros National Park*) to €4.5 billion (*A flood and heat proof green Emscher valley*), with 6 out of the 25 river restoration projects costing tens of millions of Euros. The scale of

these larger projects makes evaluation and comparison difficult as they are likely to consist of multiple smaller schemes using multiple measures and the overall biophysical impacts are often not stated. Where biophysical impacts are quantified they often use different measures (water storage vs. flow reduction) or are over incomparable timescales (flow reduction in m³/second vs. m³/day) where conversion to a common measure might not be appropriate.

There are two cases studies that allow a simple comparison of cost-effectiveness as they report water storage volumes:

- *Renaturation of the Seymaz river*, Switzerland, €61 million with 800,000 m³ of water storage = €76.3/m³
- *Restoration of the Ernz Blanche river*, Luxembourg, €2,940,000 with 110,000 m³ of water storage = €26.7/m³

The physical scales of these projects are not easily comparable (40 hectares for the Seymaz River vs. 10 kilometres for the Ernz Blanche River) and other important contextual information such as river discharge baselines are not provided.

The Sigma Plan in Belgium has an overall budget of €1.1 billion, flood protection benefits are estimated at €736m, this suggests the programme would not pass a strict cost/benefit test, however the wider ecosystem services benefits are estimated as ranging between €143 and €983 million. The *Lisbon: nature-based solutions* case study identified €7.5m per annum of ecosystem service co-benefits from 42,247 street trees compared to management costs of €1.7m per annum. One study (*Restoration on Comana wetlands*, Box 2) provided non-monetary benefits citing 10,000 tourism and recreation visits; 5,000 visits for camping, walking, jogging, water sports and cycling (unclear whether these are additional to the 10,000 visits); and 500 educational visits per year.

Details on the *Tamera Water Retention Landscape* project in Portugal (Box 3) reported on Climate-ADAPT suggest the outcome of the cost-benefit analysis was a negative net present value (-€262k). However, when separately examining costs and benefits, it is not clear why such a result is drawn. Estimates of the benefits of the project for tourism are estimated at €810K between 2014 and 2050, whereas increased value of land between €150-400k. Moreover, many other co-benefits have not been estimated in monetary terms (e.g. increase in carbon storage). Estimates of the costs of this project (NWRM, no date; BASE, no date) indicate a cost of approximately €500k. It is not clear from the estimated benefits why the net present value would be negative unless the reported values (from 2014 to 2050) have not been discounted, Climate-ADAPT does report that the outcome is sensitive to choice of discount rate, and notes that many benefits have not been quantified. This indicates that the information available does not allow us to draw definitive conclusions on the cost effectiveness of EbA measures.

One wetland restoration study (*Rehabilitation of heaths and mires on the Hautes-Fagnes Plateau*) estimated the economic benefits. Biodiversity and recreation benefits were estimated to be €1 million, this compares to the €4.5 million cost of the project. However the benefits of the increased water storage (e.g. avoided flood damages) are not monetised so a full cost-benefit assessment was not possible.

The *Slowing the flow* case study (see Box 1) is also of interest as it is a rare example of a study where a valuation of the benefits of the project has been undertaken. In this case the

range of expected ecosystem service and other co-benefits were valued, specifically related to the 85 ha woodland planting element of the project. That analysis suggests that the benefits associated with woodland planting could total €270,450, the largest elements being habitat creation and carbon sequestration at €140k and €123k respectively. Comparison with the cost of implementing that particular measure €54,277 (planting costs and loss of agricultural production) suggests a benefit/cost ratio of 4.98 which comfortably exceeds investment criteria. This is noteworthy as the project was initiated as expected flood damages in nearby town of Pickering (North Yorkshire, UK) were not sufficient to pass a benefit/cost test for hard engineered flood defences.

3.3 Ecosystem service co-benefits

One of the strengths of EbA measures is that they generate significant co-benefits, in addition to enhancing climate change adaptation and DRR. Different measures are associated with different co-benefits. Based on our review of the evidence for individual measures rather than case studies, Figure 5 illustrates the frequency with which ecosystem service co-benefits are associated with each EbA category. The figure combines the co-benefits across individual EbA measures with the colour indicating whether the impact is associated with few, most or all measures within each EbA category (to account for differing numbers of case studies for each EbA category). The figure does not represent the scale of impacts and care should be taken in across category comparisons.

EbA measures usually have positive impacts on ecosystem services. Given the focus of adaptation and Eco-DRR on the reduction in hazards, the ecosystem service benefits are most commonly related to regulating services, in particular mass and water flows, and to a lesser extent wind and local climate (temperature) regulation. As noted in the previous section the identification of wider ecosystem service co-benefits is often an important success factor in securing funding and support for implementation. However, very few of the case studies explicitly quantify ecosystem service co-benefits (either in biophysical or economic terms), as considered in section 3.2 above these include:

- *Slowing the flow*: €270k/yr from 85ha of woodland planting;
- *An integrated plan*: €143m to €984m from 2458ha of river restoration and managed realignment ;
- *Lisbon: nature-based solutions*: €7.5m from 42,247 street trees, and
- *Tamara Water Retention Landscape*: €150k to €400k social and environmental benefits.

However, EbA can also have unintended negative consequences that need to be considered. For instance, some EbA measures (e.g. water retention) can lead to an increase in insect pests (e.g. mosquitoes), which can have negative impacts on human health and wellbeing or on crop and animal health (NWRM, 2015; McVittie et al., 2017)). Some coastal measures may reduce public access to the beaches and the shoreline. Negative impacts such as this will influence the acceptability of EbA measures and need to be taken into account in planning and implementation. Several measures show both positive and negative impacts. This reflects potential trade-offs, which indicate where attention should be directed to ensure successful implementation. For example:

- Agricultural food production (crop yields, reduction in agricultural land) or wild food such as fish (improved water quality, new aquatic habitats);
- Changing types of natural habitats (move from terrestrial to coastal wetlands); and
- Different recreational activities (new recreational opportunities or restricted access or activities).

3.4 Success and limiting factors

There are a number of common factors that contribute to success across the case studies (examples of case studies cited in this paper are given with reference to their number in the Appendix, our wider database will have further examples):

- Stakeholder engagement and attitudes (3, 5, 7, 14, 16, 17, 19, 20, 26, 28, 34, 35, 37, 39, 41, 42, 44, 50, 51)
- Cooperation across stakeholders (1, 5, 7, 23, 26, 29, 31, 32, 34, 39, 41, 43, 44, 50)
- Alignment of activities across agencies including shared institutional structures (17, 26, 29, 31, 32, 34, 39, 44)
- Existing knowledge and/or on-going research and monitoring (4, 7, 13, 14, 15, 19, 23, 26, 29, 42, 44, 48, 50)
- Demonstration of private benefits (10, 16, 28)
- Demonstration of co-benefits (28, 33, 44, 52)
- Availability of finance (21, 25, 27, 29, 32, 33, 35, 36, 37, 51)
- Multiple sources of finance linked to multiple benefits (33)

The limiting factors largely reflected instances where the success factors could not be applied (examples of case studies cited in this paper are given with reference to their number in the Appendix, our wider database will have further examples):

- Lack of finance for measure implementation or land acquisition/compensation (3, 4, 5, 26, 36, 48, 52)
- Poor stakeholder engagement and negative attitudes (5, 16, 19, 29, 31, 35)
- Cooperation and consent across multiple landowners (13, 16, 21, 27)
- Lack of land or space constraints for implementation (1)
- Time lags in observing benefits (14, 29, 41)

Extensive existing knowledge and ongoing monitoring were important in several case studies including *Rural runoff attenuation in the Belford catchment*, *Slowing the Flow at Pickering* and *Eddleston Water project*. These were tied to academic research studies and technical expertise from relevant environmental agencies.

The availability of land and land ownership were potential limiting factors, particularly where land was perceived as being changed from agriculture to less valuable uses. Having a trusted stakeholder group (e.g. the Tweed Forum in the *Eddleston Water project*) can be an innovative way to overcome these constraints and to bring different interests together with public agencies and the research community. Land ownership patterns were also important in the *Slowing the Flow at Pickering* project where ownership was concentrated with 50% of the catchment being either in public ownership or owned by the Duchy of Cornwall. The barrier of high agricultural land use value was noted in *Reforestation in the Veneto*. However, the opportunity to overcome this was hindered where land use change mechanisms such as forest planting grants were reduced (*Slowing the flow*). The identification of ecosystem service co-benefits was also an important innovation the Veneto project as it allowed the development of a payment for ecosystem services (PES) scheme to deliver the project.

Although flood risk reduction may not have been a primary objective of some studies (e.g. biodiversity was often an important driver), it was found that demonstrating that flood risk benefit was important in increasing public support for measures. Having a network of interventions within a larger scale project was also mentioned as a success factor in one case

study (*Órbigo river ecological status improvement*). This contrasts with another study (*Restoration within the Srebarna Nature Reserve*) which found that river basin wide impacts were insignificant, this made assessment difficult. Other studies noted that lack of knowledge of local conditions and poor monitoring and adaptive management were also limiting factors.

The demonstration of multiple benefits was also important in identifying different financing sources. In particular, two case studies in Romania (*Ecological restoration of the Gera Pond* and *Ecological restoration of Mata Radeanu*) noted increases in bird numbers which helped to achieve biodiversity objectives. Demonstrating ecosystem service co-benefits was an important success factor (*Babina restoration project*) and can help mobilise different funding sources (agri-environment payments in *Exmoor Mires peatland restoration*).

Undertaking cost benefit analysis (often together with Environmental Impact Assessment) was used to demonstrate the effectiveness of a number of case studies, however in one case study (*Addressing coastal erosion in Marche region, Italy*) this analysis was seen as too limited in that it concentrated on tourism values. Two of the case studies (*Titchwell Marsh* and *Hesketh Out Marsh* both UK) illustrate potential trade-offs in the habitat creation associated with management realignment, in both cases there was a potential loss of breeding grounds for some bird species. These losses either meant a redesign of the project or the compensatory measures elsewhere. Compensation, whether in terms of land or financial was a key factor in a number of the studies.

Attitudes can be limiting, particularly with respect to local authorities as these measures are often unfamiliar. This limitation can be overcome through demonstrating the lessons learnt from previous applications. The measures can also be combined with hard engineering. Greater regulation such as planning controls in urban areas also offer the possibility to include EbA elements into planning conditions for development and building regulations. This in turn opens up potential funding sources from developers, although as one study (*Urban green roofs in Helsinki*) noted green roofs can add 45% to the structural costs of new industrial buildings, this cost was found to outweigh the potential benefits indicating a continuing role for public financing (subsidies) for some measures. The availability of finance (including compensation) and legal obligations can contribute both to success and act as a constraint. Similarly the degree or lack of existing knowledge, communication and institutional coordination can influence success. *Floodplain reconnection in the Vallei van de Grote Nete* was part of the much larger Sigma Plan programme, this allowed it to utilise existing capacity and encouraged inter-agency cooperation and stakeholder consultation. One particularly innovative project (*Landscape revitalisation programme*) introduced a competitive element to achieve higher value, although was hindered by the large number of small measures being implemented.

The *Tamera Water Retention Landscape* project was innovative in that the Tamera Ecovillage was able to mobilise publicity and private funds, this may also have allowed the measures to be implemented without prior authorisation (illegally) with permission then sought retrospectively. The case study does note that this type of private funding is not typically available to farmers and that public finance would be required to implement the measure elsewhere. Legal restrictions served to slow down implementation in the *Burgas lakes* case study. Existing knowledge was also important for the success of *Tamera* and *Burgas lakes*, whereas lack of knowledge hindered *Atanasovsko Lake*.

4 Conclusion

Ecosystem-based approaches such as EbA and Eco-DRR address the crucial links between climate change, biodiversity and sustainable land management and, by preserving and restoring ecosystem functioning, enabling society to achieve these multiple objectives.

Our analysis of the evidence for the impacts of EbA measures highlights a number of common themes. There are a large number of EbAs and these have been applied either individually or in different combinations across a wide range of scales. The scale of application is key, as this determines the extent to which adaptation and DRR outcomes (or co-benefits) can be observed. In many case studies EbA measures have not been applied at an appropriate scale to determine impacts such as flood risk reduction. Further, given that cooperation across multiple land owners or restrictions in the availability of land have been cited as limitations in several case studies, it is important that issues of scale can be addressed. This might involve identifying appropriate agencies to promote EbAs or redesigning funding mechanisms to reward or require cooperation.

The demonstration of multiple co-benefits may be important both where these co-benefits provide private benefits for land managers and wider societal benefits that can attract a variety of funding sources. Recognising where gaps arise between private and social costs and benefits, and what policy mechanisms are available to address those gaps is an important element in encouraging uptake. Whilst some applications of EbA measures can be encouraged through regulation (e.g. planning conditions in urban settings) many are essentially voluntary and need to be incentivised regardless of private benefits.

It should be recognised that negative impacts may be associated with some EbA measures. These may be in terms of the opportunity cost of land use change associated with agricultural (whether related to type of management or land cover), forestry, coastal and water management. Some coastal measures have also been linked to loss or damage to natural habitats. Some measures may also have negative ecosystem service impacts such as increased pests and restrictions on types of use by people. Both private and social benefits may only be achieved a number of years after implementation. This creates barriers to uptake and acceptability, and demonstrates the need for ongoing stakeholder engagement throughout both planning and implementation. Engagement with different stakeholders may also be best achieved through trusted intermediaries or agencies.

The nature of the evidence provided in the case studies was also variable. This was both in terms of the degree of quantification and the consistency of what was reported such as the units used or baselines. This may reflect the fact that climate adaptation was not the primary driver in many case studies; instead the objectives may have been biodiversity improvement, water quality or agricultural productivity. Greater awareness of adaptation or DRR potential as well as wider ecosystem service co-benefits in study design, monitoring and reporting may address this issue.

Related to the gaps around reporting of biophysical impacts is the nature of economic evidence being collected and reported. Efficient decision making, particularly when resources are constrained and facing competing demands, requires a good economic basis. Cost-benefit analysis requires both costs and expected benefits to be quantified and monetised. Cost-effectiveness analysis is useful in comparing alternative measures and

programmes, in particular when not all benefits or costs can be monetised, as it is often the case with ecosystem based approaches. However, impacts should be in common units to allow cost per unit effectiveness to be calculated.

Four broad policy recommendations emerge from this analysis. First, mainstreaming nature based solutions in policies and plans at early stages facilitates implementation. This requires an understanding of the objectives of the measure, and calls for a synergistic approach between climate change adaptation and disaster risk management. Nature-based solutions are part and parcel of the European Union's policy and research agendas, including on climate change and disaster risk reduction, as outlined in Faivre et al (this issue).

Policy mainstreaming is however not enough: funding instruments need to accompany the policy framework to foster adoption and implementation. This challenge is reflected in the analysis of the case studies summarised in this paper. Mainstreaming might also facilitate the multiple funding sources across policy streams that were identified as a key success factor in several cases. Funding under the EU Rural Development Regulation (and Member States' Rural Development Plans) could be better targeted to provide EbA and Eco-DRR outcomes through better integration across agencies, for example with respect to the Floods Directive.

Third, the participation and buy-in of local stakeholders is critical for the successful implementation of EbA and Eco-DRR measures. For instance, cities' decisions in areas like building plans and codes, flood management, urban planning, will make the difference, and can support or hinder the rolling out of nature based solutions to tackle climate change and natural hazards. Rural development payments could also be used to encourage land manager cooperation to achieve action at sufficient scale.

And finally, improving our understanding of the short and long term costs and benefits of EbA measures, of the impacts of uncertainties on the effectiveness of ecosystem-based approaches, and on alternative options available is critical. The EU's Research and Innovation Policy can play an important role in this regard.

In conclusion, mainstreaming climate change adaptation and disaster risk reduction objectives through ecosystem approaches in policies and funds, engaging local and regional actors, and filling the knowledge gaps are essential components for nature-based solutions contributing to climate action.

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Appendix

The following table provides sources and weblinks for the specific case studies mentioned in the paper. The full list and summary details of identified case studies is available in supplementary materials or from the corresponding author.

Case study name	Country	Source	Weblinks(last access 12/01/17)
1. A flood and heat proof green Emscher valley	Germany	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/a-flood-and-heat-proof-green-emscher-valley-germany
2. A transboundary depoldered area for flood protection and nature: Hedwige and Prosper Polders	Netherlands Belgium	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/a-transboundary-depoldered-area-for-flood-protection-and-nature-hedwige-and-prosper-polders
3. Addressing coastal erosion in Marche region	Italy	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/addressing-coastal-erosion-in-marche-region-italy
4. Agroforestry: agriculture of the future? The case of Montpellier	France	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier
5. An integrated plan incorporating flood protection: the Sigma Plan (Scheldt Estuary)	Belgium	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=5002
6. Babina Restoration Project	Romania	NWR M	http://www.nwrm.eu/case-study/babina-restoration-project-romania
7. Climate-adapted management of the Körös-Maros National Park	Hungary	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=3331
8. Coastal protection by managed realignment, Titchwell Marsh	UK	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/coastal-protection-by-managed-realignment-titchwell-marsh
9. Constructed wetland in Vidrăre	Bulgaria	NWR M	http://www.nwrm.eu/case-study/constructed-wetland-vidrare-bulgaria
10. Cover Crops and No-Tillage in an Olive Grove (Andalusia)	Spain	NWR M	http://www.nwrm.eu/case-study/cover-crops-and-no-tillage-olive-grove-andalusia-spain
11. Ecological reconstruction of the Gerai Pond	Romania	NWR M	http://www.nwrm.eu/case-study/ecological-reconstruction-gerai-pond-romania
12. Ecological Restoration of Mata Radeanu	Romania	NWR M	http://www.nwrm.eu/case-study/ecological-restoration-mata-radeanu-romania
13. Eddleston Water Project	UK	weA DAPT	https://www.weadapt.org/placemarks/maps/view/1140
14. Exmoor Mires peatland restoration	UK	NWR M	http://www.nwrm.eu/case-study/exmoor-mires-peatland-restoration-uk

Case study name	Country	Source	Weblinks(last access 12/01/17)
15. Ezousas artificial groundwater recharge of treated effluent	Cyprus	NWR M	http://www.nwrm.eu/case-study/ezousas-artificial-groundwater-recharge-treated-effluent-cyprus
16. Flood breaking hedgerows in Southern France	France	NWR M	http://www.nwrm.eu/case-study/floodbreaking-hedgerows-southern-france
17. Floodplain reconnection in the Vallei van de Grote Nete	Belgium	NWR M	http://www.nwrm.eu/case-study/floodplain-reconnection-vallei-van-de-grote-nete-belgium
18. Floodplain restoration in the Lonjsko Polje Nature Park	Croatia	NWR M	http://www.nwrm.eu/case-study/floodplain-restoration-lonjsko-polje-nature-park-croatia
19. Germasogeia riverbed artificial groundwater recharge	Cyprus	NWR M	http://www.nwrm.eu/case-study/germasogeia-riverbed-artificial-groundwater-recharge-cyprus
20. Green roofs in Basel, Switzerland: combining mitigation and adaptation measures	Switzerland	Clim ADA PT	http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=5801
21. Green roofs in Vienna	Austria	NWR M	http://www.nwrm.eu/case-study/green-roofs-vienna-austria
22. Kruibeke Bazel Rupelmonde (Belgium): a Controlled Flood Area for flood safety and nature protection	Belgium	Clim ADA PT	http://climate-adapt.eea.europa.eu/viewmeasure?ace_measure_id=5101
23. Landscape revitalisation program	Slovakia	NWR M	http://www.nwrm.eu/case-study/landscape-revitalisation-program-slovakia
24. Lisbon: Nature-based Solutions (NBS) Enhancing Resilience through Urban Regeneration	Portugal	OPPL A	http://info.oppla.eu/nbs/lisbon
25. Lower Danube Green Corridor: floodplain restoration for flood protection	Bulgaria Romania Ukraine Moldova	Clim ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/lower-danube-green-corridor-floodplain-restoration-for-flood-protection
26. Managed Aquifer Recharge in Los Arenales (Segovia)	Spain	NWR M	http://www.nwrm.eu/case-study/managed-aquifer-recharge-los-arenales-segovia-spain
27. Multi-purpose water management development along the Körös-ér	Hungary	NWR M	http://www.nwrm.eu/case-study/multi-purpose-water-management-development-along-k%C3%B6r%C3%B6s-%C3%A9r-hungary
28. No Tillage Field Trials in lower Austria	Austria	NWR M	http://www.nwrm.eu/case-study/no-tillage-field-trials-lower-austria
29. Órbigo River ecological status improvement	Spain	NWR M	http://www.nwrm.eu/case-study/%C3%B3rbigo-river-ecological-status-improvement-spain
30. Preservation of floodplain forests	Slovakia	NWR M	http://www.nwrm.eu/case-study/preservation-floodplain-forests-slovakia

Case study name	Country	Source	Weblinks(last access 12/01/17)
31. Rain gardens for the Day Brook	UK	NWR M	http://www.nwrm.eu/case-study/rain-gardens-day-brook-uk
32. Recovery of dried out communities	Slovakia	NWR M	http://www.nwrm.eu/case-study/recovery-dried-out-communities-slovakia
33. Reforestation in Veneto	Italy	NWR M	http://www.nwrm.eu/case-study/reforestation-veneto-italy
34. Rehabilitation of heaths and mires on the Hautes-Fagnes Plateau	Belgium	NWR M	http://www.nwrm.eu/case-study/rehabilitation-heaths-and-mires-hautes-fagnes-plateau-belgium
35. Renaturation of the Seymaz river	Switzerland	NWR M	http://www.nwrm.eu/case-study/renaturation-seymaz-river-switzerland
36. Restoration of Amalvas and Žuvintas Wetlands	Lithuania	NWR M	http://www.nwrm.eu/case-study/restoration-amalvas-and-%C5%BEuvintas-wetlands-lithuania
37. Restoration of Atanasovsko Lake	Bulgaria	NWR M	http://www.nwrm.eu/case-study/restoration-atanasovsko-lake-bulgaria
38. Restoration of the Ernztal river	Luxembourg	NWR M	http://www.nwrm.eu/case-study/restoration-ernztal-river-luxembourg
39. Restoration on Comana wetlands	Romania	NWR M	http://www.nwrm.eu/case-study/restoration-comana-wetlands-romania
40. Restoration within the Srebarna Nature Reserve	Bulgaria	NWR M	http://www.nwrm.eu/case-study/restoration-within-srebarna-nature-reserve-bulgaria
41. Restoring the River Quaggy in London	UK	NWR M	http://www.nwrm.eu/case-study/restoring-river-quaggy-london-uk
42. Rural runoff attenuation in the Belford catchment	UK	NWR M	http://www.nwrm.eu/case-study/rural-runoff-attenuation-belford-catchment-uk
43. Saltmarsh recreation by managed realignment, Hesketh Out Marsh	UK	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/saltmarsh-recreation-by-managed-realignment-hesketh-out-marsh-uk
44. Slowing the Flow at Pickering	UK	NWR M	http://www.nwrm.eu/case-study/slowing-flow-pickering-uk
45. Small scale measures under the 'Waters neighbourhood Days' in Hamburg	Germany	NWR M	http://www.nwrm.eu/case-study/small-scale-measures-under-waters-neighborhood-days-hamburg-germany
46. Small Water Retention Program in Forests (lowlands)	Poland	NWR M	http://www.nwrm.eu/case-study/small-water-retention-program-forests-lowlands-poland
47. Stuttgart: combating the heat island effect and poor air quality with green ventilation corridors	Germany	Clim ate- ADA PT	http://climate-adapt.eea.europa.eu/metadata/case-studies/stuttgart-combating-the-heat-island-effect-and-poor-air-quality-with-green-ventilation-corridors

Case study name	Country	Source	Weblinks(last access 12/01/17)
48. Tamera water retention landscape	Portugal	Clim ate-ADA PT BASE FP7 NWR M	http://climate-adapt.eea.europa.eu/metadata/case-studies/tamera-water-retention-landscape-to-restore-the-water-cycle-and-reduce-vulnerability-to-droughts http://base-adaptation.eu/water-retention-landscape-restore-water-cycle-and-reduce-vulnerability-droughts-tamera-portugal http://www.nwrm.eu/case-study/water-retention-spaces-reforestation-and-grazing-management-southern-portugal
49. Urban green roofs in Helsinki	Finland	NWR M	http://www.nwrm.eu/case-study/urban-green-roofs-helsinki-finland
50. Water retention management in the broader area of Ancient Olympia, Elia	Greece	NWR M	http://www.nwrm.eu/case-study/water-retention-management-broader-area-ancient-olympia-elia-greece
51. Wetland management on the Burgas lakes	Bulgaria	NWR M	http://www.nwrm.eu/case-study/wetland-management-burgas-lakes-bulgaria
52. Wetland restoration in Persina	Bulgaria	NWR M	http://www.nwrm.eu/case-study/wetland-restoration-persina-bulgaria

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Top 10 risks in terms of likelihood		Top 10 risks in terms of impact		
1.	Large-scale involuntary migration	1.	Failure of climate-change mitigation and adaptation	Economic
2.	Extreme weather events	2.	Weapons of mass destruction	Environmental
3.	Failure of climate-change mitigation and adaptation	3.	Water crises	Geopolitical
4.	Interstate conflict	4.	Large-scale involuntary migration	Societal
5.	Natural catastrophes	5.	Energy price shock	Technological
6.	Failure of national governance	6.	Biodiversity loss and ecosystem collapse	
7.	Unemployment or underemployment	7.	Fiscal crises	
8.	Data fraud or theft	8.	Spread of infectious disease	
9.	Water crises	9.	Asset bubble	
10.	Illicit trade	10.	Profound social instability	

Figure 1 Top ten risks in terms of likelihood and impact (adapted from WEF, 2016)

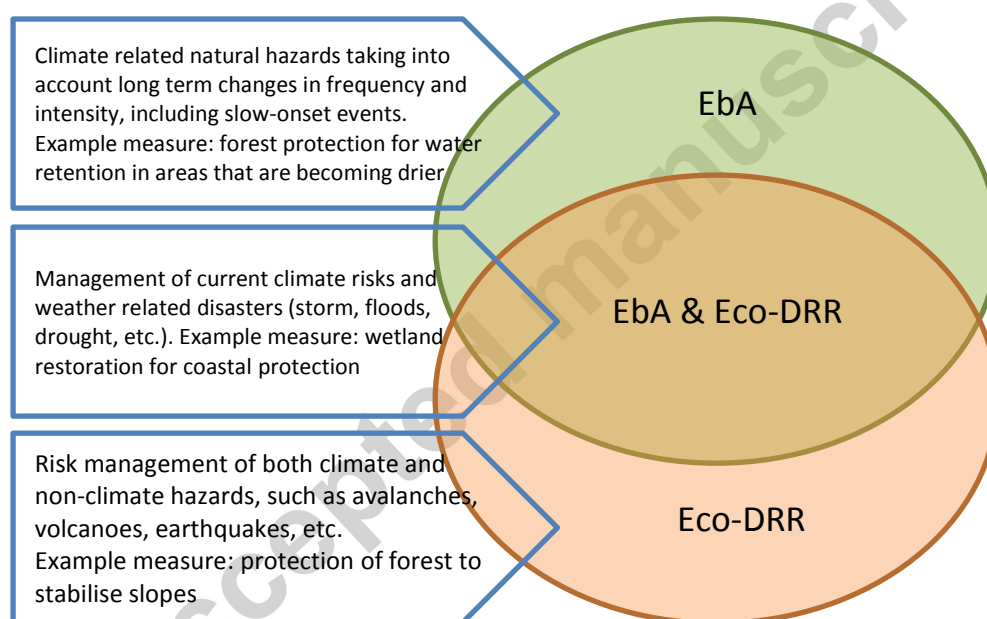


Figure 2 Some linkages between climate change adaptation and disaster risk reduction (adapted from CBD, 2016)

	Agricultural habitats	Agricultural management	Forest planting	Forest management	Coastal	Green infrastructure	Blue infrastructure	River restoration	Floodplain restoration	Groundwater restoration	Lake restoration	Wetland restoration
Wind: providing protection from erosion and damage due to more frequent high winds												
Temperature change: providing shading and other cooling effects												
Precipitation: mitigating the impact of more intense rainfall events and flooding												
Storm surge: mitigating the impact of more frequent and higher storm surges												
Sea level rise: mitigating rising sea levels												
Water scarcity/drought: maintaining supply to ground and surface waters												

Figure 3 Climate hazards that can be dealt with by different EbA categories (source: authors)

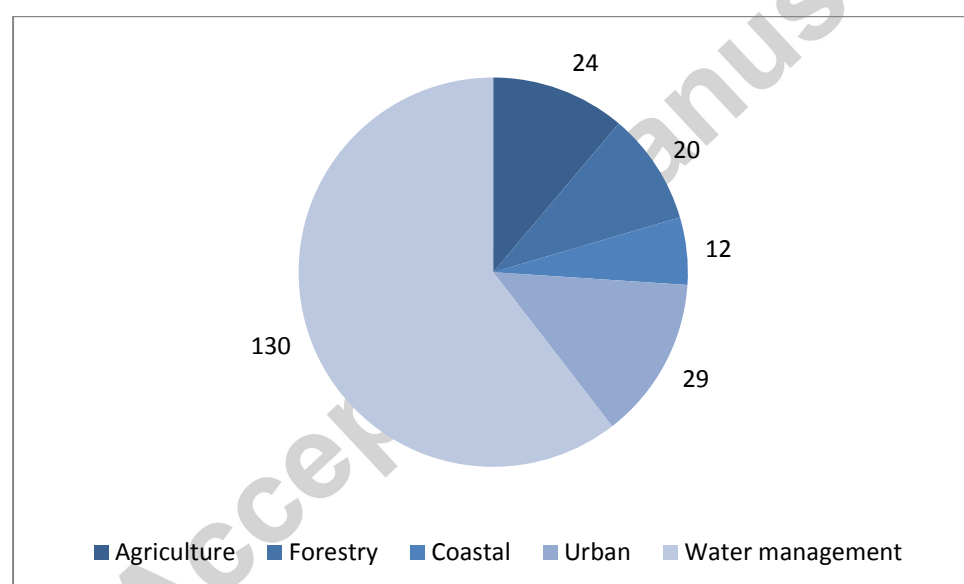


Figure 4 Number of EbA applications by category (the total of 215 measures applied across 125 case studies demonstrates the common application of multiple measures, source: authors)

	Agricultural habitats	Agricultural management	Forest planting	Forest management	Coastal	Green infrastructure	Blue infrastructure	River restoration	Floodplain restoration	Lake restoration	Wetland restoration
Biomass for food	+/-	+/-	+/-	+	+/-	+		+/-	+/-	+	+

	Water for drinking			+	+							
	Biomass for fibre/raw materials	+		+/-	+				+	+	+	+
	Water for irrigation/Livestock	+	+	+	+				+			
	Biomass for energy	+		+	+							
Regulating	Mediation of waste by biota	+		+			+	+	+			
	Mediation of waster by ecosystems	+	+	+	+		+	+	+	+	+	+
	Soil erosion	+	+	+	+	+	+	+	+	+	+	+
	Water flows	+	+	+	+	+	+	+	+	+	+	+
	Wind and ventilation flows	+		+	+		+	+	+			
	Habitats and biodiversity	+	+	+	+	+/-	+	+	+	+	+	+
	Pest and disease control/Pollination	+		+	+		+	-	-			
	Soil formation and composition	+	+	+	+			+	+	+	+	+
	Water quality	+	+	+	+		+	+	+	+	+	+
	Climate regulation	+	+	+	-		+	+	+			
Cultural	Physical and experiential interactions	+		+/-	+	+/-	+	+	+	+	+	+
	Intellectual interactions	+		+	+			+	+			
	Spiritual or emblematic interactions	+										

Impacts across all measures
 Impacts across most measures
 Impacts across few measures
 + Impacts are positive
 - Impacts are negative
 +/- Both positive and negative impacts

Figure 5 Frequency that ecosystem service co-benefits are associated with different EbA categories (frequency is based on occurrence within each EbA category, source: authors)

Box 1 Slowing the flow at Pickering (UK)

The town of Pickering in North Yorkshire has a history of flood events, most recently in 1999, 2000, 2002 and 2007; the last of these causing an estimated €8m of damage. A hard engineered flood alleviation scheme was proposed but deemed unaffordable under national cost-benefit thresholds. The 'Slowing the Flow at Pickering' project implemented multiple EbA measures including low level bunds (flood basins), woody debris dams, and woodland planting (in riparian zones, floodplains and farmland). The aim of the project is to show how land management measures can help to reduce flood risk from a river in the town and is implemented in close cooperation with local stakeholders.

Measures implemented

- Basins and ponds
- Coarse woody debris
- Forest riparian buffers

Biophysical impacts

The surrounding catchment (6860 ha) was extensively modelled and the estimated impacts of the project were:

- Increased water storage (bunds): 90,000-138,000 m³
- Peak flow rate reduction (riparian woodland and woody debris dams): 10.7% (range 6.7-14.7% depending on size of flood event)
- Flood peak delayed by 20 minutes

Economic impacts

The total costs of the project was estimated as: €1,580,000, of which:

- Low level bunds: €1,320,000
- Riparian woodland: €17,951
- Large woody debris dams (150): €27,782
- The estimated loss of agricultural output if 85ha of woodland planted was €36,326/yr

In addition to providing information on the costs of the project, there was also an economic valuation of the ecosystem service co-benefits. Based on 85 ha of woodland planting these were estimated as €270,450/yr, of which:

- Habitat creation: €139,683/yr
- Flood regulation: €6855/yr
- Climate regulation: €123,029/yr
- Erosion regulation: €236/yr
- Education and knowledge: €16/yr
- Community development: €631/y

Source: Slowing the Flow at Pickering (2015)

Box 2: Restoration in the Comana wetlands (Romania)

Reconstruction of Comana Wetland was undertaken to conserve the biodiversity, the natural habitats, the wild species of flora and fauna and to assure an efficient management of Natura 2000 protected natural areas. Beyond providing improvements in habitat resilience the main adaptation benefit is increased water retention.

Measures implemented

- Floodplain restoration and management
- Removal of dams and other longitudinal barriers

Area

- 1180 ha

Biophysical impacts

- Retention rate of 6.9 million m³
- Water quality improvement
- Land available as habitat for bird species was increased by at least 30% and the number of birds increased by at least 5%.

The cultural ecosystem service benefits of the site include

- 10,000 tourism and recreation visitors to protected sites per year
- 5,000 users for camping, nature walks, jogging, water sports, cycling per year
- 500 educational excursions per year

Success factors

- Availability of EU funding
- Strong local support due to strong awareness, Giurgiu County Council has a good collaboration with the Local Environmental Protection, and stakeholders, support from supported by Administration of Natural Park Comana who is also one of the partner within the project.

Limiting factors:

Barriers for the implementation of the measures were due to the process of public procurement for contracts regarding the supply/works/services resulting in delayed implementation, Addendum required to extend implementation period - inflexibility to redistribute savings

Source: Restoration in the Comana wetlands (2015)

Box 3: Tamera water retention landscape (Portugal)

Tamera, a farm of 154 ha, is located in an arid region of Portugal. The area has shown trends of increasing erosion and desertification. A “Water Retention Landscape” has been created comprised of a system of lakes and of other retention systems, and also including other structures such as terraces, swales and rotational grazing ponds.

Measures implemented

- Lake restoration
- Targeted planting for 'catching' precipitation
- Land use conversion
- Continuous cover forestry
- Crop rotation
- Traditional terracing
- Basins and ponds
- Swales

Economic impacts

The biophysical impacts of the project have not been fully assessed but the socio-economic effects have been estimated:

- Cost of five largest lakes: €509,000
- Increase in carbon storage of 9.4 %/year (2006-2014).
- Tourism €810,000 (between 2014 and 2050).
- Social and environmental benefits of increased water retention via market value of land €150,000 to €400,000

Success factors

- The knowledge and information of the people responsible for designing the WRL, in particular adapted to the local climate;
- The capacity to convince and mobilize the ecovillage of Tamera to take on this multi-functional investment.
- Use of communication and publicity capacity of the Tamera Ecovillage to raise private funds.

Limiting factors

- Lack of financial investment.
- Legal/regulatory framework constraints particularly around cutting of cork trees.
- Traditional farmers consider regulatory framework (CAP – Common Agricultural Policy) a big condition for climate adaptation.
- Some farmers consider that the legal framework can be a big obstacle while other consider the public payments to farmers a very important incentive

Source: Tamera water retention landscape (2015)

Table 1 Ecosystem-based adaptation and Eco-DRR measures by land use or land cover category

Category	Broad measure	Example measures ^a	Impact addressed
Agriculture	Agricultural	• Agro-forestry and crop diversification	• Floods

Forestry	habitats	• Buffer strips and hedgerows • Improved water retention in agricultural areas	• Flash floods • Drought
	Agricultural management	• Meadows and pastures • Crop rotation • Low till agriculture • No till agriculture • Green cover	
	Forest planting	• Reforestation • Afforestation • Forest riparian buffers • Land use conversion • Maintenance of forest cover in headwater areas	• Climate change mitigation • Land slides • Floods • Heat waves
	Forest management	• Water sensitive forest management • Coarse woody debris • Continuous cover forestry	
Coastal		• Beach nourishment • Coastal managed realignment • Dune reinforcement and strengthening • Cliff stabilisation	• Sea level rise • Storm surges • Land slides
Urban	Green infrastructure	• Green roofs • Rain gardens • Soakaways • Swales	• Urban greenspace • Urban forest parks • Urban trees and forests • Heat waves • Flash floods • Floods
	Blue infrastructure	• Basins and ponds • Channels and rills • Detention Basins • Filter Strips • Infiltration basins • Permeable surfaces	• Retention Ponds • Sediment capture ponds • SUDS • Temporary flood water storage
Water management	River restoration	• Elimination of riverbank protection • Natural bank stabilisation • Re-meandering • Reconnection of oxbow lakes and similar features • River restoration and rehabilitation • Riverbed material re-naturalization • Stream bed re-naturalization	• Floods • Flash floods
	Floodplain restoration		
	Groundwater restoration		
	Lake restoration		
	Wetland restoration		

^a see Climate-ADAPT (no date), NWRM (2015) and Estrella and Saalisma (2013, Table 2.1) for definitions and descriptions of these measures