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THE CASE FOR MAINSTREAMING NATURE-BASED SOLUTIONS INTO INTEGRATED CATCHMENT MANAGEMENT IN IRELAND

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ABSTRACT

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The intensification of European policies, agreements and regulations for climate action, water resources, energy, agriculture and forestry, and biodiversity is pressurising governments to adopt a wider portfolio of actionable solutions that are more financially and socially sustainable as well as scalable. Traditional engineering solutions, such as grey infrastructure, are the standard approach to the management of waterways, particularly when it comes to water purification and flood prevention or abatement. However, grey infrastructure depreciates over time, necessitating costly and technology dependant interventions on a continual basis. Green infrastructure, on the other hand, often appreciates over time and can provide multiple co-benefits in the longer term; this is the nature-based solution approach. This paper outlines the potential of nature-based solutions and integrated catchment management. It describes how current integrated catchment policy and programmes would benefit from this new approach and posits that nature-based solutions are a complimentary technology that would have multiple co-benefits in the Irish landscape.

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INTRODUCTION

Many planners and policymakers are increasingly drawing from an ecosystem approach to establish multifunctional green infrastructure for mitigating the negative and socially undesirable impacts of climate change, and this often is focussed in urban settings (e.g. Derksen *et al.* 2017; Gill *et al.* 2007; Shih 2016; Sussams *et al.* 2015; Zolch *et al.* 2016). Green infrastructure has been identified as a key engineering as well as societal solution with respect to riparian areas and flood alleviation (Alves *et al.* 2019; EEA 2017; Li *et al.* 2020; Raška *et al.* 2019; Zellner *et al.* 2016). Many definitions and conceptualisations of green infrastructure exist, but the most useful in the context of this paper is a 'strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings.' (EU 2013, p. 8). This infers that green infrastructure has a high potential for implementing many sustainable land-use policies through the scaling out of 'nature-based solutions'. These solutions, which are inspired by nature and natural processes, are designed to complement engineered/technical solutions to mitigate disaster risk and the effects of climate-related flooding whilst augmenting social and cultural values (EEA 2015, 2017). 'Nature-based solutions' is

a new term in the lexicon of planners, managers and policymakers, the definition of which is still contested (Eggermont *et al.* 2015; Faivre *et al.* 2017; Frantzeskaki *et al.* 2019). Bridgewater (2018), for example, contends that 'nature' is largely an undefined entity in the nature-based solution concept while Frantzeskaki *et al.* (2019) argue that it ought to be integrated with other solutions such as technology-based or culture-based solutions, although currently there are few working examples of this.

In the Irish planning and management policy, 'nature-based solutions' is as yet an unfamiliar term, although some local authorities are beginning to explore the implications of the idea (e.g. DCC 2019; SDCC 2018). However, much of the nature-based solution debate is concerned with the regreening of cities (Connop *et al.* 2016) as is evidenced by the plethora of nature-based solution EC Horizon 2020 projects that are in progress at this time. The projects are producing a variety of outputs such as technical guidelines for designers and managers (e.g. Eisenberg and Polcher 2019) or compendia of nature-based solution examples for planners and city-makers (such as UNEP 2019). European rural funding for enhanced biodiversity is being deployed in EIP and LIFE projects (e.g. the Bride project and Duhallow LIFE project). These place the stakeholders and communities in leadership positions to effect grass-roots change and work closely with all participants

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to develop solutions. However, the purpose of this paper is to examine the impediments to popular acceptance of the nature-based solution approach outside cities, especially on a topic where Ireland is perceived to have a high climate risk: flooding.

NATURE-BASED SOLUTIONS

Nature-based solutions are: ‘actions which are inspired by, supported by or copied from nature’ which result in ‘multiple co-benefits for health, the economy, society and the environment, and thus they can represent more efficient and cost-effective solutions than more traditional approaches’ (EC 2015). Eggermont *et al.* (2015) has proposed three types of nature-based solutions:

- Type 1: those that follow the IUCN approach and see them as mechanisms for managing and restoring protected ecosystems;
- Type 2: those that fit the broad theme of the agri-environment for augmenting the sustainability and multifunctionality of managed landscapes;
- Type 3: those that follow the EC definition and seek to (re)create ecosystems in heavily impacted areas, such as cities.

A unified and agreed upon definition still eludes practitioners and researchers, but it is clear that a nature-based solution is not merely green infrastructure or the result of valuing newly recognised ecosystem services. Ideally, a nature-based solution is specifically designed, or preferably co-designed, to address multiple, interconnected problems (ecological, environmental, social, etc.), in a manner that has multiple co-benefits (also ecological, environmental and social, etc.). Thus, it follows that the solution in question ought to be competitive with non-nature-based, or technology-based, solutions that are developed to address the same problem.

Examples of nature-based solution implementation in Ireland are few, and as such Irish policymakers could greatly benefit from the compilation of a compendium of nature-based solutions, especially with respect to their efficacy in addressing, for example, the Sustainable Development Goals (SDGs). However, some nature-based solutions do exist and mainly relate to urban water management (for examples of some Irish nature-based approaches, see LGMA Research 2020). A noteworthy example can be seen in the recent extension of the LUAS tram system in Dublin, which saw the adoption of a nature-based approach by embedding street trees in extensive pits to mitigate the effect of storm-water along the line, a successful nature-based solution strategy that is being adopted in other city schemes such as the Liberties Greening Strategy (DCC 2015). While there are few physical examples, there are even less where the effectiveness or impact

of the nature-based solution has been measured over a longer term. In other cities, such as London, a nature-based solution approach has been adopted over a longer timeframe, and a strong evidence base has been built on the co-benefits of such an approach (Connop *et al.* 2016).

In the riparian zone, nature-based solutions have the potential for flood relief, building flood resilience, mitigating point source or diffuse pollution to the environment, intercepting silt and/or acid runoff from forestry and peatland management activities, and so on (Hartmann *et al.* 2019; Liqueste *et al.* 2016). The idea is not necessarily new; nature-based solutions that have been in operation in the landscape for some time include those in place for the management and control of nutrient runoff, such as the use of

- vegetated buffer zones in riparian areas for point-source and diffuse nutrient runoff (especially N and P) in agri-environmental contexts (Aguilar Jr *et al.* 2015; Hille *et al.* 2018; Janssen *et al.* 2018; Stutter *et al.* 2019; Vought *et al.* 1995),
- constructed wetlands for sewage and runoff management (Mitsch 1992; Shutes 2001),
- catch crops to reduce nutrient leaching (Constantin *et al.* 2010),
- broadleaved woodlands to buffer the effects of episodic acid runoff in conifer afforested areas and acid-sensitive zones (Collier and Farrell 2007; Ryan *et al.* 2012),
- *Salix* spp. (and other biomass plantations) to treat excess nutrient (Bialowiec *et al.* 2012) and sewage (Börjesson and Berndes 2006), as wind-breaks (Foereid *et al.* 2002), for phytoremediation (e.g. Xue *et al.* 2015), water purification (Perttu and Kowalik, 1997), and so on.

However, in these examples the ‘nature’ that is being utilised may not necessarily be biodiverse nature, as the species selected to achieve maximum efficacy and impact may not be, for example, indigenous or diverse. So, while this might qualify to be termed as nature-based solutions there is little regard for the social, ecological, economic and behavioural co-benefits that the current nature-based solution framework entails.

DISCUSSION

Although nature-based solutions have only recently entered the purview of mainstream policymakers, there is now a compelling business case (EIB 2018), an emerging health and well-being cases (Han and Hyun 2018; van den Bosch and Ode Sang 2017a, b; Vujcic *et al.* 2017) and a strong biodiversity case (Nash *et al.* 2019; Seddon *et al.* 2019; The Nature Conservancy 2018) for incorporating nature-based solutions into planning and design of urban and

rural landscapes. When it comes to river catchment restoration and management one may assume that a nature-based solution approach would result in multiple benefits over a longer term. However, those responsible for river catchment management in Ireland may feel that they are applying nature-based solutions in practice. In this context, three approaches to river catchment management can be identified. These approaches, whilst seeming to be nature-based in principal, are not necessarily in alignment with the nature-based solution ideals in practice.

The first approach best describes the principal management practice in Ireland and which falls under the legal jurisdiction of the Office of Public Works (OPW) (Gutman 2019). In river catchment management, the OPW carries out drainage maintenance and manage larger infrastructural flood relief schemes (OPW 2019), especially dredging in order to permit faster flow. Their approach to riparian management can be described as ‘hard’ engineering solutions, such as mechanised channel clearance and construction of defensive embankments along rivers (Brew and Gilligan 2019). There is an ambition to integrate what is perceived as essential works with ‘nature’, and these guidelines provide management prescriptions for specific protected species. However, the OPW is confined in its actions by the immediate political and societal demand for protection of property. Such management also needs to be aligned with the legal requirements of, for example, the Water Framework Directive (WFD), the Habitats Directive and the Birds Directive (EEC 1979, 1991, 1992).

For flood risk management, the OPW prepares flood plans as a central part of the government policy on flood risk management. This is intended to meet Ireland’s obligations under the 2007 EU ‘Floods’ Directive (FD). To this end there has been a recent change in OPW’s direction. First, it is committed to work with the Environment Protection Agency, local authorities and other agencies during the project-level assessments of physical works and more broadly at a catchment-level to identify any natural water retention measures (NWRM) that can have benefits for the WFD, flood risk management and biodiversity objectives. Second, it has identified that local level of activity may provide a suitable point of coordination for local flood risk management activities such as flood protection works being implemented under the Minor Works Scheme or the promotion of natural water retention measures. Third, it has mandated that consideration be given to ensure that the planned works provide benefits with regards to other objectives in the delivery of the EIP (e.g., water quality, biodiversity) where reasonably possible and viable these may include the use of NWRM, removing barriers to fish migration

or the creation of habitat features. Although at present, there is no transparent mechanism for ensuring the delivery of the ‘alternatives’ to harder engineering approaches or indeed the definition of ‘viable’ in the context of flood risk. Finally, the OPW has set up a Natural Water Retention Measures Working Group to advise the WFD National Technical Implementation Group (NTIG) on proposals for including NWRM as part of a broader suite of mitigation measures that could contribute to the achievement of environmental objectives set out in the second RBMP. While this is positive, there is no doubt that we await the implementation of many aspirations. This, in combination with a general lack of awareness of the potential of nature-based solutions, can make decision-making, in the absence of a nature-based solution decision support framework in Ireland, difficult and may result in the imposition of grey infrastructure into the riparian zone to the medium-term detriment of ecological processes. Thus, while the nature-based solution approach may be ideal, in practice it is necessary to draw on existing, validated engineering standards and in many cases this results in blunt, hard engineered solutions.

The second approach is the desire for taking a ‘soft’ engineering solution approach. This is also in the purvey of the OPW (2019), but considering their legal imperative it is often the case that ecological engineering companies and contractors, often independent of the OPW, are in a better position to work to a more local context. Resulting actions are variable, but generally—and comparison with the deepening of riverbeds through dredging and other hard processes—this second approach works to stabilise revetments and banks along rivers and streams using a combination of hard (e.g. gabions) and soft (e.g. *Salix* spp. establishment) solutions. Thus, this approach seeks to draw from some nature-based principals in order to restore riverbanks (e.g. Barker 1995), though there can be less concentration on a diversity of species in preference for species that will do a good engineering job. In the initial phase of this approach there can be a considerable amount of stream adjustment and mechanical manipulation, as with the hard engineering approach of the OPW, but in the concluding part of the process, when ecological interventions are being put in place, the morphology of the riparian zone appears to be more ‘natural’. This process may appear to follow a nature-based solution framework, but where both approaches fall short is in the derivation of multiple social and economic co-benefits, one of the central aspirations of the nature-based solution approach. One of the main barriers to adopting such an approach is whether nature-based solutions can ‘compete’ effectively with non-nature-based solutions. This barrier derives from equating effective riparian restoration to a reduction in downstream flooding

(i.e. protection of property), rather than a more holistic assessment on whether the resulting riparian system is self-regulating, requires no further engineered interventions and yields increases in ecosystem service values over a longer timeframe. This is an area that has not yet been quantified, and the above-mentioned Horizon 2020 projects are seeking to establish this case.

A third approach addresses longer term riparian management and ecosystem service values from a grounded angle and relies at its core on a collaborative, community driven and generally more inclusive consultation process. This approach is typified by a complex co-creation process with local communities and a supporting fund (such as the Community Water Development Fund through the Local Authority Waters Programme (DoHPLG 2018) <http://watersandcommunities.ie/>). While mostly focussing on education and empowerment, this approach also supports local wetland research and ecological restoration beyond the catchment. It is targeted at a longer-term cost-effective paradigm because it is coupled with education and awareness programmes and habitat creation, so it appears to embrace a nature-based solution framework. However, where this third approach is not wholly a nature-based solution approach is in the monitoring and evaluation of a wide range of indicators of efficacy. Such indicators include water quality enhancement, climate resilience, increasing biodiversity, participatory governance, community health and well-being, social cohesion and innovation. While the Horizon 2020 projects mentioned earlier—and the current focus within the European Green Deal—all seek to develop monitoring and evaluation indicators, there is no mechanism in Ireland for the measurement of the co-benefits of nature-based solutions (either in river catchment management or in other areas). This is therefore a principal barrier to mainstreaming nature-based solutions in Ireland, though one that could be rectified with little additional cost.

That said, the component parts do exist. The nature-based solution approach to river catchment management seeks to combine the efficacy and immediacy of the first two engineered approaches with the collaborative and co-created approach of the third. What remains is for this to be embedded with a comprehensive effectiveness monitoring and programme that quantifies the multiple co-benefits of river catchment management, in scale and over time (Addy *et al.* 2016) as the absence of evidence of the efficacy of nature-based solutions for flood mitigation remains a significant obstacle (e.g. Dadson *et al.* 2017). Thus, it is simultaneously aimed at targeted, local-scale interventions of nature-based solutions that combine cumulatively for catchment scale effectiveness. This nature-based approach has not yet become established in the Irish context

(and is still emerging on a global context) though there is strong case for it (Addy *et al.* 2016). This approach has the aspiration of implementing a 'multifunctional form of green infrastructure that can play an important role in catchment-scale flood risk management' (Collentine and Futter 2018, p. 76). There are some local-scale interventions in existence in Ireland, such as blocking drains to rewet degraded peatlands (Farrell and Doyle 2000; 2003; Renou-Wilson *et al.* 2018). Of import is the rise of the River Trusts in Ireland. Although it varies across the country, their mandate ranges for community-level education about riverbank erosion controls to catchment-scale plans for nature-based solutions to flooding hazards (e.g. Bourke *et al.* 2020). In other jurisdictions, local scale interventions such as species rewilding (e.g. the (re)introduction of the beaver) have shown excellent promise in flood management on a catchment scale (Law *et al.* 2017), and while such interventions can engender political and social concern, they offer a tantalising insight into the co-benefits of nature-based solutions for both addressing climate-related issues and biodiversity restoration. It is perhaps an opportunity to establish whether local-scale interventions may be cost-effective as well as socially desirable, something that would assist in addressing the SDGs.

Already mentioned as a barrier is the lack of knowledge by stakeholders. Other jurisdictions have undertaken assessments of barriers in landowners' perceptions (Holstead *et al.* 2017; Waylen *et al.* 2018). A similar assessment in the Irish context is required as the limited data available (Buckley *et al.* 2016; Buckley *et al.* 2012; Clarke *et al.* 2016) suggest that the socio-economic aspect may be a significant barrier to implementation.

CONCLUSIONS

The approaches discussed here appreciate the role that 'nature' can play in the management and control of flooding, though each conceptualises the values of nature differently. The 'hard' engineering approach can regard nature as peripheral to the more urgent societal expectation of alleviating flooding. The 'soft' engineering approach views nature as supplemental element of the overall solution and as such the species selected are those who have the best short-term impact (such as fast-growing *Salix* spp.) over a longer-term biodiversity focus. In both of these approaches nature may be viewed as peripheral. The alternative approach views nature as having multiple benefits (co-benefits) and these values include educational, research and awareness values, but is very localised. All three approaches can be classed as nature-based in some degree of intensity, though the nature in question is not necessarily

indigenous. In all approaches, wider societal, cultural and health co-benefits are usually not accounted for, indicators of effectiveness are limited in scope, and monitoring is at best *ad hoc*. The nature-based solution approach sees these as integral to the process from the outset.

It is clear that Ireland must make diverse, systemic changes in order to mitigate flooding episodes and that there is a compelling case for using a nature-based solution approach to both tackle immediate concerns but also to build longer term resilience and biodiversity into management practices. It is also clear that more effort needs to be made to improve knowledge, experience and capacity in adapting existing catchment management policies, regulations and activities to embed nature-based solutions for climate adaption. Thus, there needs to be better coordination on flood management planning, especially in the longer term and with co-benefits at the forefront of planning.

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REFERENCES

- Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A. and Holstead, K. 2016 River Restoration and Biodiversity: nature-based solutions for restoring the rivers of the UK and Republic of Ireland. Aberdeen, IUCN NCUK and CREW.
- Aguiar Jr, T.R., Raseira, K., Parron, L.M., Brito, A.G. and Ferreira, M.T. 2015 Nutrient removal effectiveness by riparian buffer zones in rural temperate watersheds: the impact of no-till crops practices, *Agricultural Water Management* **149**, 74–80.
- Alves, A., Vojinovic, Z., Kapelan, Z., Sanchez, A. and Gersonius, B. 2020 Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation, *Science of The Total Environment* **703**.
- Barker, D.H. 1995 Vegetation and slopes: stabilisation, protection and ecology: proceedings of the international conference held at the University Museum, Oxford, 29–30 September 1994, Thomas Telford.
- Bialowiec, A., Davies, L., Albuquerque, A. and Randerson, P.F. 2012 Nitrogen removal from landfill leachate in constructed wetlands with reed and willow: redox potential in the root zone, *Journal of Environmental Management* **97**, 22–7.
- Börjesson, P. and Berndes, G. 2006 The prospects for willow plantations for wastewater treatment in Sweden, *Biomass and Bioenergy* **30**(5), 428–438.
- Bourke, M.C., Halpin, R., Brady, F. Quinn, P.F. 2020 The Opportunity for Natural Water Retention Measures in Inishowen, Ireland. A report prepared for the Inishowen Rivers Trust. Dublin, Consult Trinity.
- Brew, T. and Gilligan, N. 2019 Environmental Guidance: Drainage Maintenance and Construction, in: *Ecological Assessments on Arterial Drainage Maintenance Series: No 13. Environment Section*. Trim, Office of Public Works.
- Bridgewater, P. 2018 Whose nature? What solutions? Linking Ecohydrology to Nature-based solutions, *Ecohydrology and Hydrobiology* **18**(4), 311–16.
- Buckley, C., Howley, P., O'Donoghue, C. and Kilgarraff, P. 2016 Willingness to pay for achieving good status across rivers in the Republic of Ireland, *The Economic and Social Review* **47**(3), 425–45.
- Buckley, C., Hynes, S. and Mechan, S. 2012 Supply of an ecosystem service – farmers' willingness to adopt riparian buffer zones in agricultural catchments, *Environmental Science and Policy* **24**, 101–09.
- Clarke, D., Murphy, C. and Lorenzoni, I. 2016 Barriers to transformative adaptation: responses to flood risk in Ireland, *Journal of Extreme Events* **03**(02), 1650010.
- Collentine, D. and Futter, M.N. 2018 Realising the potential of natural water retention measures in catchment flood management: trade-offs and matching interests, *Journal of Flood Risk Management* **11**(1), 76–84.
- Collier, M.J. and Farrell, E.P. 2007 The Environmental Impact of Planting Broadleaved Trees on Acid-sensitive Soils. Dublin, COFORD.
- Connop, S., Vandergert, P., Eisenberg, B., Collier, M.J., Nash, C., Clough, J. and Newport, D. 2016 Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure, *Environmental Science and Policy* **62**, 99–111.
- Constantin, J., Mary, B., Laurent, F., Aubrion, G., Fontaine, A., Kerveillant, P. and Beaudoin, N. 2010 Effects of catch crops, no till and reduced nitrogen fertilization on nitrogen leaching and balance in three long-term experiments, *Agriculture, Ecosystems and Environment* **135**(4), 268–78.
- Dadson, S.J., Hall, J.W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I.P., Lane, S.N., O'Connell, E., Penning-Rowsell, E., Reynard, N., Sear, D., Thorne, C. and Wilby, R. 2017 A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the

- UK, *Proceedings of the Royal Society A* **473**(2199), 20160706.
- DCC (Dublin City Council) 2015 The Liberties Greening Strategy. Dublin, Dublin City Council.
- DCC (Dublin City Council) 2019 Nature-based Solutions, in: *Dublin County Council Draft Climate Action Plan - Nature-based Solutions*. Dublin, Dublin City Council pp. 84–91.
- Derkzen, M.L., van Teeffelen, A.J. A. and Verburg, P.H. 2017 Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences?, *Landscape and Urban Planning* **157**, 106–30.
- DoHPLG (Department of Housing, Planning and Local Government) 2018 River Basin Management Plan for Ireland 2018–2021. Dublin, Government of Ireland.
- EEA (European Environment Agency) 2015 Exploring Nature-based Solutions: the role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards, Technical Report No 12/2015. Luxembourg, European Environment Agency.
- EEA (European Environment Agency) 2017 Green Infrastructure and Flood Management: promoting cost-efficient flood risk reduction via green infrastructure solutions. Copenhagen, European Environmental Agency.
- EEC (European Economic Community), 1979, Council Directive 79/409/EEC on the conservation of wild birds, European Economic Communities, Luxembourg.
- EEC (European Economic Community) 1991 Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Luxembourg, European Economic Communities.
- EEC (European Economic Community) 1992 Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora. Luxembourg, European Economic Communities.
- Eggermont, H., Balian, E., Azevedo, J.M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W.W. and Le Roux, X. 2015 Nature-based solutions: new influence for environmental management and research in Europe, *GAIA - Ecological Perspectives for Science and Society* **24**(4), 243–48.
- EIB (European Investment Bank) 2018 Investing in Nature: financing conservation and nature-based solutions. Luxembourg, European Investment Bank.
- Eisenberg, B. and Polcher, V. 2019 Nature-based Solutions - Technical Handbook 1, UNaLab Horizon 2020 Project.
- EU (European Union) 2013 Building a Green Infrastructure for Europe. Luxembourg, Official Publication of the European Communities.
- Faivre, N., Fritz, M., Freitas, T., de Boissezon, B. and Vandewoestijne, S. 2017 Nature-Based Solutions in the EU: innovating with nature to address social, economic and environmental challenges, *Environmental Research* **159**, 509–18.
- Farrell, C.A. and Doyle, G.J. 2000 Rehabilitation management of industrial cutaway Atlantic blanket bog, *Biology and Environment: Proceedings of the Royal Irish Academy* **99B**, 52–53.
- Farrell, C.A. and Doyle, G.J. 2003 Rehabilitation of industrial cutaway Atlantic blanket bog in County Mayo, North-West Ireland, *Wetlands Ecology and Management* **11**, 21–35.
- Foeroid, B., Bro, R., Mogensen, V.O. and Porter, J.R. 2002 Effects of windbreak strips of willow coppice - modelling and field experiment on barley in Denmark, *Agriculture, Ecosystems and Environment* **93**, 25–32.
- Frantzeskaki, N., McPhearson, T., Collier, M.J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., van Wyk, E., Ordóñez, C., Oke, C. and Pintér, L. 2019 Nature-based solutions for urban climate change adaptation: linking science, policy, and practice communities for evidence-based decision-making, *BioScience* **69**(6), 455–66.
- Gill, S.E., Handley, J.F., Ennos, A.R. and Pauleit, S. 2007 Adapting cities for climate change: the role of the green infrastructure, *Built Environment* **33**(1), 115–33.
- Gutman, J. 2019 Commentary: Urban Wetlands Restoration as NBS for Flood Risk Mitigation: From Positive Case to Legitimate Practice, in the View of Evidence-Based Flood Risk Policy Making, in T. Hartmann, L. Slavíková and S. McCarthy (eds) *Nature-based flood risk management on private land: disciplinary perspectives on a multidisciplinary challenge*. Cham, Switzerland, Springer.
- Han, H. and Hyun, S.S. 2018 Green indoor and outdoor environment as nature-based solution and its role in increasing customer/employee mental health, well-being, and loyalty, *Business Strategy and the Environment* **28**(4), 629–41.
- Hartmann, T., Slavíková, L. and McCarthy, S. 2019 *Nature-Based Flood Risk Management on Private Land*. Switzerland, Springer Open.
- Hille, S., Andersen, D.K., Kronvang, B. and Baattrup-Pedersen, A. 2018 Structural and functional characteristics of buffer strip vegetation in an agricultural landscape - high potential for nutrient removal but low potential for plant biodiversity, *Science of the Total Environment* **628–629**, 805–14.
- Holstead, K.L., Kenyon, W., Rouillard, J.J., Hopkins, J. and Galán-Díaz, C. 2017 Natural flood management from the farmer's perspective: criteria that affect uptake, *Journal of Flood Risk Management* **10**(2), 205–18.
- Janssen, M., Frings, J. and Lennartz, B. 2018 Effect of grass buffer strips on nitrate export from a tile-drained field site, *Agricultural Water Management* **208**, 318–25.
- Law, A., Gaywood, M.J., Jones, K.C., Ramsay, P. and Willby, N.J. 2017 Using ecosystem engineers as tools in habitat restoration and rewilding: beaver and wetlands, *Science of the Total Environment* **605–606**, 1021–30.
- LGMA Research 2020 A Profile of Local Government Climate Actions in Ireland. Dublin, Local Government Management Agency.
- Li, L., Uyttenhove, P. and Vaneetvelde, V. 2020 Planning green infrastructure to mitigate urban surface water flooding risk - A methodology to identify priority areas applied in the city of Ghent, *Landscape and Urban Planning* **194**.
- Liquete, C., Udias, A., Conte, G., Grizzetti, B. and Masi, F. 2016 Integrated valuation of a nature-based solution

- for water pollution control. Highlighting hidden benefits, *Ecosystem Services* **22**, 392–401.
- Mitsch, W.J. 1992 Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution, *Ecological Engineering* **1**(1–2), 27–47.
- Nash, C., Ciupala, M.A., Gedge, D., Lindsay, R. Connop, S. 2019 An ecomimicry design approach for extensive green roofs, *Journal of Living Architecture* **6**(1), 62–81.
- OPW (Office of Public Works) 2019 Flood Relief Schemes. Dublin, OPW.
- Perttu, K.L. and Kowalik, P.J. 1997 Salix vegetation filters for purification of waters and soils, *Biomass and Bioenergy* **12**(1), 9–19.
- Raška, P., Slavíková, L. and Sheehan, J. 2019 Scale in Nature-Based Solutions for Flood Risk Management, in T. Hartmann, L. Slavíková, S. McCarthy (eds) *Nature-based flood risk management on private land: disciplinary perspectives on a multidisciplinary challenge*, Cham, Switzerland, Springer International Publishing.
- Renou-Wilson, F., Moser, G., Fallon, D., Farrell, C.A., Müller, C. and Wilson, D. 2018 Rewetting degraded peatlands for climate and biodiversity benefits: results from two raised bogs, *Ecological Engineering* **127**, 547–60.
- Ryan, J.L., Lynam, P., Heal, K.V. and Palmer, S.M. 2012 The effect of broadleaf woodland on aluminium speciation in stream water in an acid-sensitive area in the UK, *Science of the Total Environment* **439**, 321–31.
- SDCC (South Dublin County Council) 2018 South Dublin County Council Draft Climate Action Plan, 70–77. Dublin, South Dublin County Council.
- Seddon, N., Turner, B., Berry, P., Chausson, A. and Girardin, C.A.J. 2019 Grounding nature-based climate solutions in sound biodiversity science, *Nature Climate Change* **9**(2), 84–87.
- Shih, W.Y. 2016 The cooling effect of green infrastructure on surrounding built environments in a sub-tropical climate: a case study in Taipei metropolis, *Landscape Research*, 1–16.
- Shutes, R.B.E. 2001 Artificial wetlands and water quality improvement, *Environment International* **26**(5–6), 441–7.
- Stutter, M., Kronvang, B., Ó hUallacháin, D. and Rozemeijer, J. 2019 Current insights into the effectiveness of riparian management, attainment of multiple benefits, and potential technical enhancements, *Journal of Environmental Quality* **48**(2), 236–47.
- Sussams, L.W., Sheate, W.R. and Eales, R.P. 2015 Green infrastructure as a climate change adaptation policy intervention: muddying the waters or clearing a path to a more secure future?, *Journal of Environmental Management* **147**, 184–93.
- The Nature Conservancy 2018 Nature in the Urban Century: a global assessment of where and how to conserve nature for biodiversity and human well-being. The nature Conservancy / Future Earth / Stockholm Resilience Centre.
- UNEP (United Nations Environment Programme) 2019 Compendium of Contributions Nature-Based Solutions, UNEP.
- van den Bosch, M. and Ode Sang, Å. 2017a Urban natural environments as nature-based solutions for improved public health – a systematic review of reviews, *Environmental Research* **158**, 373–84.
- van den Bosch, M. and Ode Sang, Å. 2017b Urban natural environments as nature-based solutions for improved public health – a systematic review of reviews, *Environmental Research* **158**, 373–84.
- Vought, L.B.-M., Pinay, G., Fuglsang, A. and Ruffinoni, C. 1995 Structure and function of buffer strips from a water quality perspective in agricultural landscapes, *Landscape and Urban Planning* **31**, 323–31.
- Vujcic, M., Tomicevic-Dubljevic, J., Grbic, M., Lecic-Tos-evski, D., Vukovic, O. and Toskovic, O. 2017 Nature based solution for improving mental health and well-being in urban areas, *Environmental Research* **158**, 385–92.
- Waylen, K.A., Holstead, K.L., Colley, K. and Hopkins, J. 2018 Challenges to enabling and implementing Natural Flood Management in Scotland, *Journal of Flood Risk Management* **11**, S1078–S1089.
- Xue, K., van Nostrand, J.D., Vangronsveld, J., Witters, N., Janssen, J.O., Kumpiene, J., Siebielec, G., Galazka, R., Giagnoni, L., Arenella, M., Zhou, J.Z. and Renella, G. 2015 Management with willow short rotation coppice increase the functional gene diversity and functional activity of a heavy metal polluted soil, *Chemosphere* **138**, 469–77.
- Zellner, M., Massey, D., Minor, E. and Gonzalez-Meler, M. 2016 Exploring the effects of green infrastructure placement on neighborhood-level flooding via spatially explicit simulations, *Computers, Environment and Urban Systems* **59**, 116–28.
- Zolch, T., Maderspacher, J., Wamsler, C. Pauleit, S. 2016 Using green infrastructure for urban climate-proofing: an evaluation of heat mitigation measures at the micro-scale, *Urban Forestry and Urban Greening* **20**, 305–16.