The Resilient Landscape

Introduction

In the light of recent flood events, UK policymakers are becoming increasingly concerned about flooding (Kenyon et al., 2008). The annual cost of flood damage in the UK is currently estimated at £1.1 billion and could rise to as much as £27 billion by 2080 (NAO, 2011). With extreme weather events set to become commonplace due to climate change, considerable efforts are needed to mitigate the impacts of future flood events (Evens et al., 2004; Pitt, 2008; Kenyon et al., 2008). Natural flood management (NFM) – a potentially more sustainable and cheaper alternative to traditional engineering approaches (Howgate and Kenyon, 2009) – has therefore gained both local and national interest.

Increasing tree cover is a central objective of NFM strategies and can help mitigate flooding through reducing surface run-off and increasing water storage capacity upstream (Nisbet et al., 2015). Despite growing support for woodland-based measures and NFM more broadly, there are a number of challenges to their widespread uptake. These include a number of uncertainties regarding their effectiveness, difficulties in coordinating catchment-wide action, and perverse incentives that currently discourage landowners from planting trees. Using the conceptual framework of social-ecological resilience and drawing on experience from a NFM project in North Yorkshire, this essay discusses the opportunities and challenges to increasing flood resilience through use of woodland-based measures.

Natural flood management

Traditionally, flood management has largely been the domain of hydrologists, planners and engineers with a focus on 'hard engineered' defences such as sea walls, embankments and dams (Werritty, 2006). Although hard engineered defences may prevent flooding in the short-term, their long-term sustainability is questionable (Werritty, 2006; Forbes et al., 2015). As flood risks increase, the height and strength of current defences must also be improved, resulting in substantial financial costs (Mileti, 1999; Kenyon et al., 2008; Forbes et al, 2015). In addition, hard engineered solutions may be deemed unjustifiable if the total value of properties at risk does not offset the cost of their construction and maintenance, thus leaving vulnerable communities with inadequate flood protection (POST, 2011).

In recent years, NFM has gained increasing support as a sustainable and cheaper alternative to hard engineering (Howgate and Kenyon, 2009). NFM refers to a broad suite of measures that aim to increase resilience to flooding by reducing the 'flood peak' (the maximum water height of a flood) and to delay its arrival downstream by: a) increasing water storage capacity in the upper catchment, b) improving soil infiltration and thus reducing surface run-off, and c) increasing the water storage capacity of rivers and floodplains (POST, 2011). NRM measures – also referred to as ‘soft engineering’ – utilise natural materials such as soil, trees and woody debris (POST, 2011), and include river and wetland restoration, the construction of dams, and woodland creation (Table 1). Strategically increasing tree cover within a catchment through woodland-based measures plays a central role in NFM strategies and forms the main focus of this essay.

Measure group	Measure type	Main action
Land management	Improved land and soil management practices	Runoff reduction
	Agricultural and upland drainage modification	Runoff reduction
	Overland sediment traps	Runoff reduction/sediment management
	Non-floodplain wetlands	Runoff reduction
Woodland creation	Catchment woodlands	Runoff reduction
	Floodplain woodlands	Runoff reduction/floodplain storage
	Riparian woodlands	Runoff reduction/floodplain storage
River and floodplain restoration	Riverbank restoration	Sediment management
	River morphology and floodplain restoration	Floodplain storage/sediment management
	In-stream structures (e.g. large woody dams)	Floodplain storage
	Washlands and offline storage ponds	Floodplain storage

Table 1. Examples of natural flood management measures (adapted from Forbes et al., 2015).

Defining resilience

The term ‘resilience’ is used by various scientific disciplines, from economics and engineering to ecology and sociology, each of which provide their own specific definitions (Brand and Jax, 2007). This diverse interpretation of what is meant by resilience can often cause confusion (Walker and Holling, 2004; Brand and Jax, 2007). It is therefore important to clearly define what is meant by resilience before discussing how it can be strengthened through use of NFM.

Within the field of ecology and ecosystem science, two forms of resilience are commonly defined: engineering resilience and ecological resilience (Holling, 1973, 1996; Mumby et al., 2014). Engineering resilience, considered the more traditional definition, refers to systems that recover towards the same equilibrial state following disturbance, and is measured by the speed at which variables return to their equilibrium following perturbation (Pimm, 1984; Holling, 1996). Ecological resilience on the other hand, refers to systems that can move towards one or more alternate stable states following perturbation, and is measured by the magnitude of disturbance that can be absorbed before a change in system structure occurs (Holling, 1973, 1996).

More recently, the concept of ecological resilience has been extended to address whole social-ecological systems (Walker and Holling, 2004; Adger et al., 2005) – a social-ecological system (SES) being a ‘linked system of people and nature in which people depend on nature and nature is influenced by people' (Cumming et al., 2013:1140). SESs consist of 'nested dynamics operating at particular organisational scales', often termed 'sub-systems' (Walker and Holling, 2004:2). These social and ecological sub-systems can range from households, villages and nations, to trees, forests and landscapes (Walker and Holling, 2004).

Social-ecological resilience as defined by Adger et al. (2005:1036) is 'the capacity of SESs to absorb recurrent disturbances, such as hurricanes or floods, so as to retain essential structures, processes, and feedbacks'. Therefore, to *build* resilience is to increase the capacity of a SES to cope and adapt to disturbances such as flooding (Folke et al., 2002). Carpenter et al. (2001) propose three properties of social-ecological resilience: 1) the magnitude of disturbance a system can absorb while retaining the same structure and functions, also referred to as 'resistance', 2) the degree to which the system is capable of self-organization, and 3) the degree to which the system can build capacity for learning and adaptation – also referred to as 'adaptive capacity'. Concerned with the resilience of water catchments to flooding, including the social and ecological sub-systems that exist within them, this essay focuses on the social-ecological definition of resilience and its three properties: resistance, self-organisation and adaptive capacity.

Stability landscapes

The theoretical concept of social-ecological resilience is often described using a 'stability landscape', where the analogy of a rolling ball is used to explain a system's behaviour following perturbation (Walker and Holling, 2004; Hudgson et al., 2015). In the rolling ball analogy, the state of a system (the ball) is represented along the horizontal axis, while the potential of the system to move between alternate states is described using the vertical axis (Figure 1) (Peterson et al., 1998; Hudgson et al., 2015). When the slope is steep, the system exhibits both resistance and rapid recovery, returning quickly towards a steady state following perturbation, also known as an 'attractor' (Walker and Holling, 2004).

SESs are however continually knocked and battered by both anthropogenic and natural disturbances, moving the system away a given attractor (Walker and Holling, 2004). SESs therefore tend to move about within a 'basin of attraction', which include all the initial system conditions that tend toward the same attractor (Walker and Holling, 2004). For any given SES there may be more than one basin of attraction. The potential basins a system may occupy and the boundaries between them constitute the stability landscape for that system, while the variables that make up the system determine its state and position within in it (Walker and Holling, 2004).

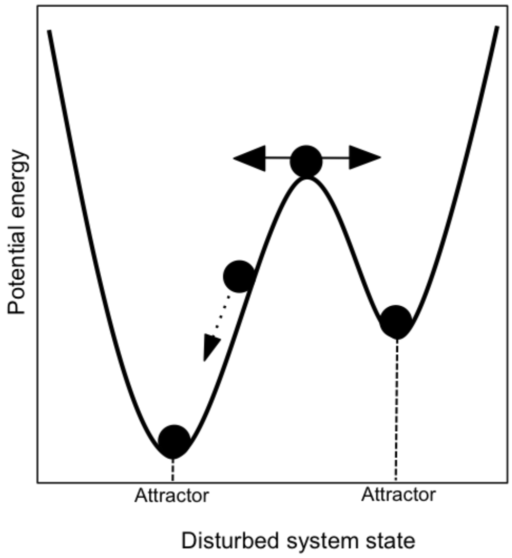

Figure 1. Conceptual representation of social-ecological resilience: each ball represents a disturbed system. If a system remains undisturbed it will settle into the bottom of a trough (an attractor). The peaks within the landscape represent the thresholds for each basin of attraction (adapted from Hudgson et al., 2015).

Although both exogenous and endogenous divers and processes can change the shape of a stability landscape, the dynamics and direction of change within SESs are largely determined by human action (Walter and Holling, 2004). Human actors within a SES may believe certain basins of attraction to be undesirable. Their management objective may therefore be to prevent a system from moving into an undesirable basin, or to actively move the system out of an undesirable basin to a more desirable one (Walker and Holling, 2004). Use of NFM can be seen as an attempt to shift a catchment and it's social and ecological sub-systems from a currently undesirable state (flood prone) to a more desirable one (flood resilient) through working with natural processes.

Building resilience: putting theory into practice

Although stability landscapes provide a useful metaphor for conceptualising resilience they provide little insight into its application and operationalization (Carpenter et al., 2001). For example 'potential energy', the unit commonly assigned to the vertical axis of a stability landscape, would be near impossible to measure for any complex SES (Hudgson et al., 2015). Stability landscapes do, however, provide general concepts that are useful when analysing SESs. For instance, SESs may be easy or difficult to change, near or far away from basin thresholds, and differ in the range of dynamics they can tolerate while remaining in the same basin of attraction (Walter and Holling, 2004). Although still difficult to measure under field conditions, these concepts can be used to identify potential indicators that are likely to change with resilience (Carpenter et al., 2001:777). For example, hydrographs, infiltration rates, and peak flows can be used to indicate how 'resistant' a given catchment is to flooding. Using a NFM demonstration project in North Yorkshire – 'Slowing the Flow' (see Box 1) – the following section explores potential indicators of resilience, and the opportunities and barriers to enhancing the resistance, self-organisation and adaptive capacity of flood-prone SESs.

Box 1. Slowing the Flow

'Slowing the Flow' is a Forestry Commission-led project based at Pickering in North Yorkshire. It is one of three pilot projects funded by Defra designed to investigate how NFM can help reduce flood risk. In 2007, floods resulted in an estimated £7 million of damage to the town of Pickering (Nisbet et al., 2011). Large-scale hard engineered defences however were believed to be unjustified given the current national cost-benefit thresholds and potential impact on the town's historical character (Nisbet et al., 2015; Roe, 2016, pers. comm., 18th March). The project therefore implemented NFM measures (Table 2) across the 69-km^2 catchment of Pickering Beck and its neighbouring catchment the River Severn to complement the construction of a large flood storage bund upstream of the town (Nisbet et al., 2015).

NFM measures	Original objectives	Implemented
Large woody dams	150	167
Riparian and floodplain woodland	80 ha	29 ha
Farm woodland	5 ha	15 ha
Blocked moorland drains	N/A	187
Improved forest drainage systems	N/A	N/A
Review of Forestry Commission felling plans	N/A	N/A
Farm-scale measures	N/A	N/A

Table 2. Natural flood management measures for both Pickering Beck and River Severn catchments (Nisbet et al., 2015).

Resistance

In regards to SESs, resistance is the magnitude of disturbance a system can absorb while retaining the same structure and functions (Carpenter et al., 2001). The following section focuses on the impact of NFM measures on flood resistance – in this case, the degree to which the Pickering Beck and River Severn catchment can resist and mitigate flooding in the town of Pickering.

Increasing flood resistance

Biophysically, resistance to flooding depends on the ability of a catchment to absorb and retain water upstream, reducing peak flows downstream following heavy rainfall (POST, 2011). Potential indicators of increased flood resistance therefore include the additional water storage provided by NFM interventions and their effect on the chance of flooding during certain sized flood events. At Pickering, Durham University's hydrological model 'OVERFLOW' was used to predict the effect of both the large flood storage bund and NFM measures. The bund, designed to protect Pickering from a 1 in 25 year event and provide 120,000 m^3 of additional flood storage, is predicted to reduce the risk of flooding from a 25% chance in any year to 4% (Nisbet et al., 2015). NFM measures are predicted to have created 8,000-9,000 m^3 of additional flood storage, further reducing the risk of flooding to a <4% chance (Nisbet et al., 2015). Although the NFM measures provide a relatively small contribution to increased flood resistance, they are expected to have greater influence with increasing flood flow (Nisbet et al., 2015; Roe, 2016, pers. comm., 18th March). For example, woodland-based measures are predicted to reduce a 1 in 100 year flood peak by 8%, compared to 4% during a 1 in 25 year event (Nisbet et al., 2015). Nevertheless, it is clear NFM measures alone are unlikely to protect Pickering from future floods, and despite their low implementation cost, would seem to be far less cost-effective in terms of additional water storage compared to the bund (Figure 2).

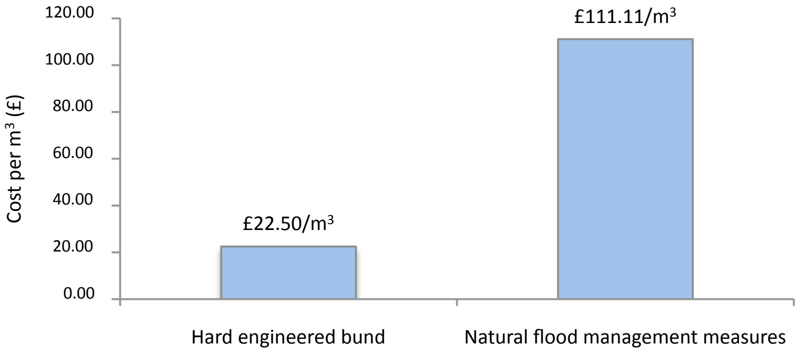

Figure 2. Cost per m^3 of flood storage gained. The flood storage bund and NFM measures cost £2.7 million and £1 million (Roe, 2016, pers. comm., 18th March), and provided an additional 120,000m^3 and 8-9,000 m^3 of storage, respectively (Nisbet et al., 2015).

Challenges

Despite the potential benefit to using woodland-based measures there are a number of potential challenges. Firstly, the location of woodland measures within a catchment greatly affects their impact on flooding. Planting trees in the lower areas of a catchment may actually increase the risk of flooding due to synchronisation of catchment contributions (Nisbet et al., 2011). 'Slowing the Flow' greatly benefited from access to hydrological data and the OVERFLOW model in order to identify where within the catchment woodland interventions would work best (Nisbet et al., 2011). Other flood-prone catchments looking to implement NFM may not be so fortunate. The potential effect on dry weather flows, also presents a risk to increasing tree cover, and may be particularly important in catchments where water demands are high (Nisbet and Thomas, 2006). In addition, fallen trees and debris washed-out from woodlands may block bridges and culverts, causing further issues downstream (Nisbet and Thomas, 2006).

Self-organisation

Self-organisation can be defined as the process of coordinated action arising from the action of individuals (Cumming, 2011). Indicators of a SES's ability to self-organise aim to measure the extent to which external forces (e.g. economic and institutional constraints) limit the ability of actors (e.g. land owners and managers) to negotiate local solutions and organise themselves in ways that promote resilience (Carpenter et al., 2001). In regards to NFM, the nature of land ownership, availability of financial incentives and the degree to which farmers are reliant on subsidies, can be used to indicate a SES's potential to self-organise.

Ownership of land and conflicting interests

Private landowners are notoriously difficult to engage in tree planting schemes (Lawrence and Dandy, 2014; Moseley et al., 2014), and are often resistant to implementing woodland measures due to a lack of financial incentive, loss of agricultural subsidies and the perceived reduction in land value (Nisbet and Thomas, 2008; Nisbet et al., 2011; Chalmers, 2016, pers. comm., 15th March; Roe, 2016, pers. comm., 18th March). A key factor in Pickering's success has been the nature of land ownership within the catchment (Roe, 2016, pers. comm., 18th March). Approximately 50% of the land is either publically owned by the Forestry Commission and North York Moors National Park Authority, or privately by the Duchy of Lancaster Estates (Nisbet et al., 2011). Their common interests and shared vision for the catchment is believed to have helped facilitate a coordinated catchment-wide approach to NFM (Nisbet et al., 2011; pers. comm. Roe, 2016). Nevertheless, riparian and floodplain woodland creation has been identified as the greatest challenge to the project, with only 29 ha planted compared to the initial goal of 80 ha (Nisbet et al., 2015).

All 40 ha identified as suitable for floodplain woodland was under private ownership (Nisbet et al., 2011). Given the high agricultural quality of this land, tree planting presented a significant loss to landowners in terms of agricultural production (Moseley et al., 2014). Despite a Forestry Commission grant rate of £1,800/ha for woodland establishment and an additional £2,000/ha as an incentive for participation, no floodplain woodlands were planted (Nisbet et al., 2015). In contrast, the presence of a community woodfuel initiative led to the establishment of 13 ha of farm woodland (Nisbet et al., 2011; Roe, 2016, pers. comm., 18th March). Woodland creation schemes tend to focus on promoting the wider benefits of forestry, such as biodiversity and carbon sequestration, rather than its contribution to a landowner's more immediate objectives (Moseley et al., 2014). Focusing on the direct benefit to an agricultural business, such as local biomass production, could help increase future engagement (Morgan-Davies et al., 2008).

Although the nature of land ownership at Pickering facilitated decision-making, tree planting was also constrained by the National Park's interest in maintaining the 'iconic open moorland landscape' (Nisbet et al., 2011:14; Roe, 2016, pers. comm., 18th March), highlighting how current public perceptions of how a landscape *should* look present potential barriers to NFM. In addition, most of the 144 ha identified as suitable for riparian woodland lay within Sites of Significant Scientific Interest (SSSI) and was therefore discounted for planting (Nisbet et al., 2011).

Policy and agricultural subsidy

Despite the potential for agriculture to be part of the solution rather than the problem, few institutional links between flood risk management and agricultural policy exist (Kenyon et al., 2008). The current Common Agricultural Policy categorises farmland occupied by trees as ineligible for the Basic Payment Scheme, thus financially penalising landowners for having trees on their farms. This loss of agricultural subsidy was a primary reason for private landowners not participating in woodland-based measure at Pickering (Moseley et al., 2014). Addressing perverse incentives that discourage landowners from planting and retaining trees must therefore be made a priority if woodland measures are to become widespread.

Trust, confidence and leadership

As previously discussed the success of woodland measures relies heavily on the cooperation of private landowners. Lack of trust between actors and confidence in authorities can present a barrier to the emergence of collaborative action in natural resource management (Pretty and Ward, 2001; Olsson and Folke, 2004). Similarly, leadership is believed to play a significant role in the process of self-organization, with key individuals often initiating important processes and building trust among stakeholders (Olsson and Folke, 2004). People's decisions are also heavily influenced by *who* communicates relevant information to them (Moseley et al., 2014). As woodland measures require the cooperation of landowners, Moseley et al. (2014), emphasise the need to identify important individuals, organisations and networks, landowners trust and have confidence in. Non-forestry organisations such as the National Farmers Union or respected farmers within the community should therefore be seen as 'gatekeepers' to private landowners, and used to increase their engagement in NFM.

Adaptive capacity

Adaptive capacity is the degree to which a SES can build capacity for learning and adaptation (Carpenter et al., 2001; Mumby et al., 2014). Indicators of adaptive capacity therefore include the presence of networks that facilitate problem solving and action, access to alternative sources of income, and mechanisms for learning and knowledge sharing (Carpenter et al., 2001). The following section focuses on the challenges and opportunities to strengthening the latter in regards to NFM and woodland-based measures.

Learning mechanisms

Learning is a crucial aspect of system adaptation and can be advanced by exploring different options, monitoring the results and making modifications based on new findings (Carpenter et al., 2001). A current lack of long-term data on the effects of NFM presents a major challenge to its implementation and widespread uptake (Howgate and Kenyon, 2009; POST, 2011). Although future monitoring under projects such as 'Slowing the flow' are hoped to improve our understanding of NFM and system dynamics, a number of challenges exist.

Quantifying changes in flood response at a catchment scale is an arduous task. In order to determine the effectiveness of NFM measures, collection of robust flow records and long-term data is required (Nisbet et al., 2015). In order to check that any change in flood response is due to NFM measures alone, data is also needed form a nearby 'control' catchment where no NFM interventions have been undertaken (Nisbet et al., 2015). Such challenges explain the heavy reliance on modelling to evaluate the impact of NFM at Pickering (Nisbet et al., 2015). Unfortunately, many of the models currently used to evaluate NFM are informed by only small-scale catchment experiments, bringing a large degree of uncertainty to the efficacy of NFM at larger catchment scales (Nisbet et al., 2015).

Knowledge sharing

The need to combine scientific knowledge and local observation is often stressed by those promoting 'adaptive comanagement' (Olsson and Folke, 2004). Adaptive comanagement involves creating platforms for collaborative learning and knowledge sharing between stakeholders on the management of ecosystems (Olsson and Folke, 2004). Through living in close association with their environment, local land managers can provide valuable information on the processes and dynamics of SESs that may otherwise go undetected by scientific research (Olsson and Folke, 2001). Not only can the use of local knowledge potentially improve management decisions (e.g. the location of NFM measures), it may also make them more acceptable to land managers themselves (Jackson et al., 2013). Use of collaborative modelling and opportunity mapping between experts, agencies and stakeholders could be used to explore spatially explicit trade-offs between NFM and stakeholder objectives, highlighting areas with the maximum potential for "win-win" scenarios (e.g. land of low agricultural value but high NFM potential) and facilitating negotiation and cross-sector collaboration (Jackson et al., 2013; Pagella and Sinclair, 2014).

Conclusion

In order to analyse the challenges and opportunities for increasing flood resilience through use of NFM measures – specifically woodland creation – this essay focused on the social-ecological definition of resilience and its three properties: resistance, self-organisation and adaptive capacity. Engaging private landowners in tree planting was seen as the greatest challenge to woodland creation under the 'Slowing the Flow' project. A number of opportunities for increasing self-organisation and adaptive capacity were therefore identified. Firstly, re-framing planting schemes within the context of current landowner objectives, addressing perverse incentives that discourage tree planting, continual learning through robust monitoring, and finally, the use of participatory modelling and mapping to facilitate negotiations and cross-sector collaboration. As illustrated by Pickering, woodland-based measures have potential to help increase flood resistance, particularly where large structural solutions may be considered unfeasible. It is however important to recognise the difficulties in their implementation, the current uncertainties surrounding their effectiveness, and to see them in complementarity with hard engineering rather than an outright alternative. In regards to the potential indicators of social-ecological resilience proposed throughout this essay, further development of robust yet cost-effective indicators will be needed if the impacts of future NFM strategies on flood resilience are to be quantified.

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