Evidence Brief—How effective are Nature-based Solutions to climate change adaptation?

Nathalie Seddon, NBSI, Department of Zoology, University of Oxford. August 2018

There is growing recognition that nature-based (or 'green') solutions—i.e. the restoration or rehabilitation and protection of natural habitats—when applied strategically and equitably can not only safeguard biodiversity and ecosystem services but also help people adapt to climate change [1,2]. The type of NbS targeted at helping people adapt to the impacts and hazards of climate change is widely referred to as "Ecosystem-based Adaptation" (EbA). The Convention on Biological Diversity (CBD) first formally coined the term EbA, defining it as "*the use of biodiversity and ecosystem services ... to help people adapt to the adverse effects of climate change" which "may include sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities.*"[3] It is often defined as being an alternative to "grey" engineering although really there is a spectrum of interventions which include components of both (i.e. hybrid or "grey-green" approaches).

Key examples include:

- *Protecting forests & wetlands in catchments* (headwaters and along rivers) to secure & regulate water supplies & protect communities from flooding, soil erosion & landslides [4-8];
- *Restoring carbon-rich coastal ecosystems* (mangroves, reefs and salt marshes) to protect communities from storm surges, salt water intrusion & erosion [9-12];
- *Planting trees among crops or crops within forest* (i.e. agroforestry) to maintain & enhance yields in drier more variable climates [13-17];
- *Creating green roofs & walls & planting trees in cities* to moderate impacts of heatwaves, capture storm water & abate pollution [18-19].

While the evidence base is still developing, it is clear that NbS can provide low risk, low maintenance and low cost solutions to many climate change related hazards and impacts [20,21].

Economic benefits of nature-based solutions—There is also growing evidence of the economic benefits of maintaining natural habitats through avoided losses to climate change related disasters. For example, coastal wetlands in northeast USA protected $625 million worth of property from direct flood damages during Hurricane Sandy, reducing damages by 20-30% in 50% affected areas with greater protection provided the greater the extent of intact wetland habitat [22]. Meanwhile, a recent global, process-based valuation across an entire marine biome at subnational levels showed that annual expected damages from flooding would double and costs from frequent storms would triple in the absence of reefs globally.

Co-benefits of nature-based solutions—In addition to these economic benefits, unlike engineered solutions to the same hazards, NbS and hybrid approaches provide multiple co-benefits (i.e. ecosystem services), such as access to food and water, pollination and soil formation, carbon storage and diversified livelihoods [23-26]. For example, 25 years of forest restoration in the Poyang Lake basin in Southern China not only halved heavy soil erosion but increased net carbon sequestration five-fold and net income for local farmers six-fold [6]. Similarly, afforestation in the Republic of Korea in 1960-2010 achieved a significant reduction of disaster risk while increasing in carbon sequestration with a break-even point of investment after 20 years [7].

Comparing nature-based solutions to alternative approaches—While studies of the effectiveness and co-benefits of NbS are growing in number, much rarer are those directly comparing NbS with alternative approaches. One recent example compared evidence for the efficacy of nature-based solutions (e.g. sand dunes, saltmarsh, mangroves, seagrass and kelp beds, and coral and shellfish reefs) relative to artificial coastal protection (e.g. seawalls and breakwaters) [27]. The study found that the latter are becoming economically and ecologically unsustainable and recommends creating

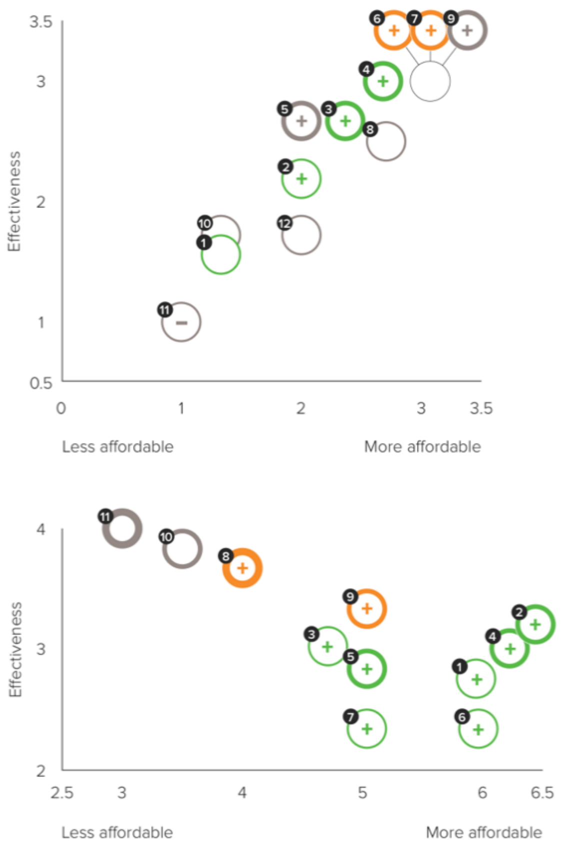

Fig. 1 Cost-effectiveness of EbA/NbS (green), engineered (grey) and hybrid (orange) adaptation approaches to **a, drought** and **b, coastal flooding.** Strength of available evidence increases with thickness of circle lines; signs within circles denote whether overall there are positive, negative or no co-benefits (e.g. ecosystem services) of the approach; numbers within circles refer to the type of adaptation approach. **a, Drought adaptation**: (1) removal of 'thirsty' invasive plant species, (2) reforestation, (3) forest conservation, (4) agroforestry, (5) breeding drought resilience crops and livestock, (6) sustainable agroecosystem management practices, (7) soil and water conservation, (8) reservoirs, points and other water storage, (9) wells, (10) irrigation, (11) inter-basin water transfer and (12) waste water re-cycling. **b, Coastal flooding adaptation**: (1) maintenance of natural reefs (coral/oyster), (2) mangrove maintenance, (3) mangrove planting and re-establishment, (4) maintenance of saltmarshes, wetlands and intertidal ecosystems, (5) creation of saltmarshes, wetlands and inter-tidal ecosystems, (6) maintenance of other coastal vegetation, (7) coastal re-vegetation/ afforestation(above inter-tidal zone), (8) beach and dune nourishment, (9) artificial reefs (and/or substrates for reef replenishment), (10) dykes, levees, (11) coastal barrages. ©The Royal Society 2014.

or restoring natural habitats in place of (or to complement) artificial structures. To date, the only study to make broader comparisons, was a semi-quantitative review of NbS, hybrid and engineered approaches to reducing risks to people from extreme weather events (coastal and riverine flooding, heatwaves, drought) using a combination of literature and expert scores and opinion [24]. This assessment compared the effectiveness of each option (encompassing both magnitude of the event against which the intervention can be effective and spatial scale over which it is effective) versus its affordability (combining both initial and long-term (to 2050) costs of intervention) (Fig. 1). It also scored intervention with respect to the number of co-benefits it brought (Fig.2).

Pros and cons—Engineered approaches to dealing with climate change impacts have immediate, measurable impacts and are particularly effective in reducing the impacts of specific hazards over the short-term. However, they are expensive and deliver few if any co-benefits. In contrast, NbS is affordable, provides a wide range of ecosystem services and offers protection from multiple hazards, which is important as hazards seldom occur in isolation but can take place simultaneously or in a cascade. For example, coastal forests can protect against coastal and inland flooding, strong winds, and high temperatures, whilst providing a range of ecosystem services and supporting more diverse livelihoods. In contrast to engineered approaches, NbS also involve and benefit local people, can be more adaptive to new conditions, and is less likely to create a false sense of security. NbS tend to be less effective than engineered structures over the short-term (i.e. effects are hard to quantify and can take time to manifest themselves), can take up larger areas of land, and involve the use of ecosystems that are themselves vulnerable to climate change. Meanwhile, hybrid approaches are intermediate in terms of effectiveness and affordability, but often have positive additional consequences. For example, two of the most affordable and effective hybrid options against drought are using 'sustainable agro-ecosystem management practices' and 'soil and water conservation'. These are bundles of separate, mutually reinforcing, small

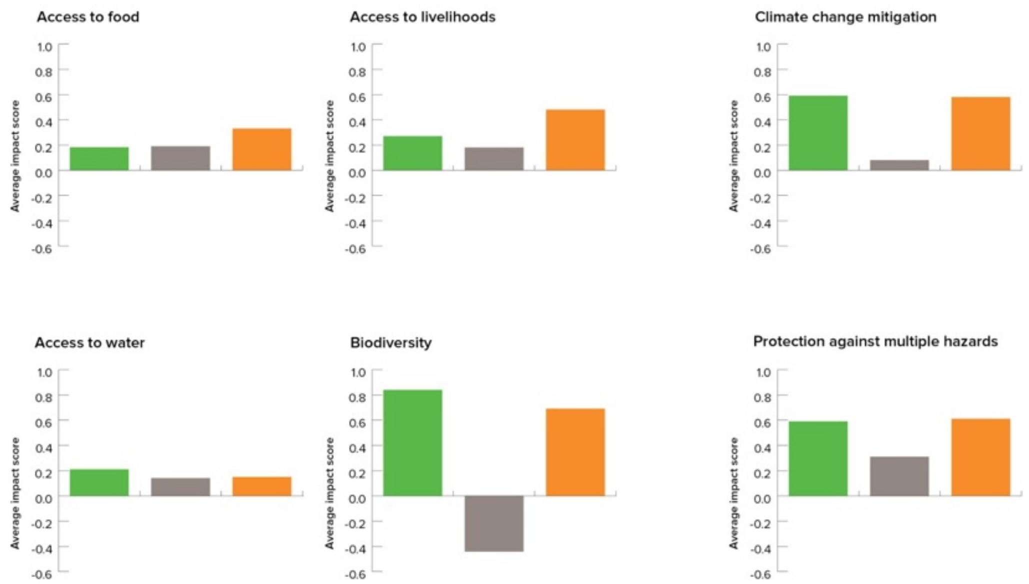

Fig 2. Additional consequences of different categories of adaptation options
Average impact score of nature-based (green), engineered (grey) and hybrid (orange) options, across all types of extreme event considered, on each additional consequence assessed. © Royal Society 2014

interventions, involving some NbS elements, changes to agricultural practices and low-tech engineering, which can be tailored to local contexts. Overall, hybrid approaches have the most positive consequences, and are marginally higher than nature-based approaches for all the factors considered in the assessment (Fig. 2).

Conclusions— Nature-based solutions can help people adapt to the effects of change and disasters whilst slowing warming and protecting biodiversity, with many more positive consequences, fewer risks and lower costs than engineering-based approaches. Decision makers should therefore consider adaptation and defensive options beyond traditional engineering including the conservation of natural ecosystems which are difficult or impossible to restore. Practitioners and researchers, meanwhile, must step up efforts to monitor and evaluate the effectiveness of interventions, in particular of NbS, and apply the results to improve future decision-making.

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