Multi-functionality of Nature-based Solutions - a systems view

A review on the applicability of System Dynamics to evaluate the social, ecological, and economic trade-offs of Nature-based Solutions

by

Willem V. Kruip[1,2,*], Lieke Hüsken[1,2], Jill H. Slinger[1,3]

1. Faculty of Technology Policy and Management, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands
2. Deltares, Boussinesqweg 1, 2629 HV Delft, The Netherlands
3. Institute for Water Research, Rhodes University, Artillery Road, Grahamstown 6140, South Africa

* Correspondence: Willem.kruip@deltares.nl

Extended Abstract

Nature-based-solutions (NbS) are defined as strategies meeting societal challenges through the utilisation of natural features or processes which simultaneously provide biodiversity and human well-being benefits. NbS examples include vegetated foreshores or mangroves for coastal surge reduction, wetlands for water retention and/or quality improvement, and tree planting for urban heat mitigation. NbS are recognised as offering the potential for adaptation (and mitigation) to climate change while strengthening biosphere integrity and societal well-being.

This literature review addresses the need for a comprehensive understanding of multi-functionality in NbS for climate change adaptation. Multi-functionality concerns the three main impact dimensions of NbS: social, ecological and economic. NbS are intrinsically complex as multiple disciplines and sectors are involved in their design and realisation, and systematically complex owing to their embedding in complex social-ecological systems which exhibit characteristics such as non-linearity or system uncertainty, and encompass multi-stakeholder environments. This combination has inhibited a comprehensive understanding of multi-functionally which has limited the successful uptake of NbS, leading the literature to urge for a holistic approach regarding multi-functionality.

The systems approach may facilitate this understanding by generating knowledge on complex system structure and behaviour. Consequently, the objective of this review is twofold: 1) To identify limitations in the understanding of the multi-functionality of NbS for CCA, 2) To assess how system dynamics modeling (SDM) as an application of the systems approach may help overcome these limitations. In this study, we focus on regional-scale NbS as these relate to a broader range of multi-functional dynamics associated with social-ecological systems.

Methods

The first objective is addressed by conducting a literature review based on a systematic search and analysis of the articles in the final selection. The overview of search terms is presented in 1, while Figure 1 depicts the search structure.

Keyword category	Search field	Keywords
Nature-based solutions	Title	"Nature-based solutions" OR "NbS"
Climate change adaptation	Title-abstract-keywords	AND "Climate change adaptation" OR "Climate resilience" OR "Climate-resilience"
Multi-functionality	Title-abstract-keywords	AND "Multi-dimensional" OR multidimensional" OR "Ecosystem-services" OR "Benefits" OR "Co-benefits" OR "Multiple benefits" OR "Added values" OR "Trade-offs" OR "Connectivity" OR "Connection" OR "Feedback" OR "Social-ecological"
Non-urban focus	Title-keywords	AND NOT "urban" OR "city" OR "cities"

Table 1: Search terms. Our regional-scale NbS scope led us to exclude articles focusing on urban areas.

The second objective is addressed by synthesizing the findings from the literature review with the expertise in systems thinking and SDM of the authors. Additionally, we carried out a heuristic literature review on previous SDM approaches in this context. The sample was built with a small selection of papers from the initial literature search and and others which were found through snowballing, consultation with experts, and a search on the keywords ”System Dynamics Modeling” AND ”Nature-based Solutions”.

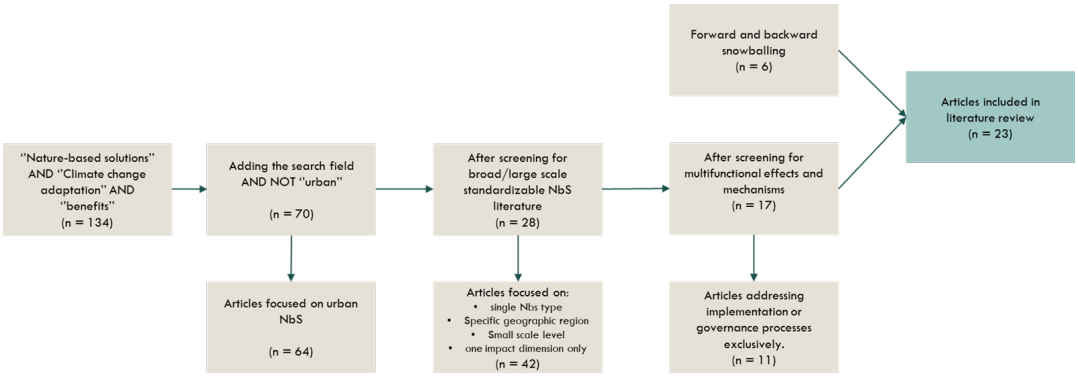

Figure 1: Literature review search structure. Note how our exclusion of urban-focused articles resulted in the exclusion of almost half of the potential results

Results

We found that there is a need for greater understanding of the trade-offs associated with various NbS strategies - over time, under climate uncertainty and for various stakeholders. The lack of integrative multi-functional analysis was especially apparent, leaving the variation in effectiveness poorly understood. summarizes the findings.

Knowledge gap	Elaboration
Lack of integrative multi-functional assessments	• Holistic assessment of multi-functionality rarely carried out • Impacts assessed in isolation • Trade-offs disregarded • Particularly social and (non-marketable) economic impacts underrepresented
Limited cross-scale assessments	• Underreporting (and assessment) of multi-functionality over the temporal and spatial scale, and under (climate) uncertainty • Limited understanding of interactions between subsystems • Few multi-NbS strategies assessed
Limited inclusion of local stakeholders	• Inclusion of local stakeholders limited • Compromising inclusion of their perceptions in identifying and valuing (multi-functional) benefits.

Table 2: Overview of knowledge gaps

The systems approach is still applied sparingly in this research area, while it aligns closely with the NbS concept and is imperative when analysing the complex dynamics of social-ecological systems. Despite being resource intensive, several key advantages in addressing the identified limitations can be attained with a systems approach, namely:

- **Transcends linear causal thinking**: It provides a comprehensive view of the numerous interactions, dependencies, and constraints within the systems where NbS are intended to function.
- **Dynamic performance evaluation**: It is well-suited for scenario analysis, with a capacity to investigate complex behaviour over time for different interventions and climate projections, which is crucial for NbS adaptation planning.
- **Facilitates Integrated Assessment**: It incorporates multiple disciplines, contextual knowledge, and the diverse values and perceptions of various stakeholders facilitating participation and understanding.

We consider SDM an appropriate application of the systems approach within the defined context. It is able to model nonlinear relationships between various sub-elements in a coupled system, include and aggregate both material and information flows, and fits the research area well due to the numerous

feedback loops that complex social-ecological systems exhibit. Yet, its application for modelling NbS multi-functionality is extremely rare in practice, especially in non-urban contexts. No system dynamics model has comprehensively addressed the limitations identified.

Future research

The necessity for further exploration of the applicability of SDM approaches to the issue of multi-functionality in NbS for climate change adaptation is evident. Essentially, this research underscores the need for an explorative SDM study that comprehensively assesses the multi-functional trade-offs of various NBS strategies - integrating aspects over time, space, under different climate scenarios and for various stakeholders. To obtain comprehensive insights in the the wideranging effectiveness of NbS, a quantitative modelling study that acknowledges uncertainty and considers multiple perspectives is recommended. Concluding, we argue that policy should embrace the complexity of NbS, and encourage the adoption of a systems thinking mindset for a holistic and comprehensive understanding of their multi-functionality.