REGREEN
NATURE-BASED SOLUTIONS

Fostering Nature Based Solutions for smart, green and healthy urban transitions in Europe and China

Deliverable **N°4.2**

WP N°4 Wellbeing assessments and valuing benefits of Nature Based Solutions

BENEFIT VALUATION OF NATURE BASED SOLUTIONS: USING CAUSAL LOOP DIAGRAMS TO DEVELOP OUR UNDERSTANDING OF THE COMPLEX SYSTEMS LINKING NBS AND HUMAN HEALTH & WELLBEING

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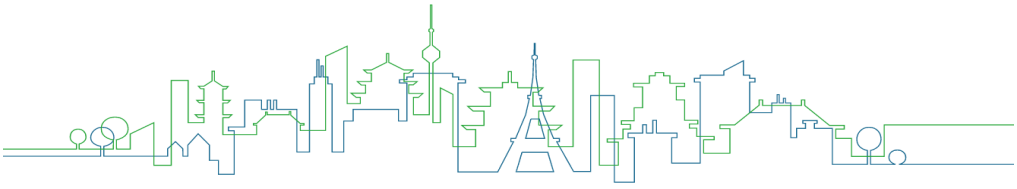

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EXECUTIVE SUMMARY

Background

Causal loop diagrams can provide a useful tool for synthesising the complex interrelationships between Nature Based Solutions (NBS) and health. Following prioritization with representatives from the Urban Living Labs (ULLs), we focused on street trees as an example of a NBS with the potential to reduce the heat island effect, improve air quality, increase carbon sequestration, and improve the quality of living environments. We define street trees as trees growing alongside public roads, regardless of whether they are managed by local authorities or by private individuals or corporations.

The burden of disease around mental health is high and projected to increase. Finding population level strategies to avoid, reduce and mitigate poor mental health is a key priority globally. Interest in the potential of street trees to help adapt to the consequences of environmental change, whilst sequestering carbon and contributing to better health and wellbeing outcomes is growing.

While links between nature and mental health, urban trees and mental health, and overall benefits of street trees have been documented in a number of reviews, the links between street trees and mental health remain less clear. This report provides important insights into the use of causal loop diagrams in unpicking the complexities.

Methods

We undertook a complexity-informed synthesis which assessed how street trees as a NBS may interact with the existing complex system around mental health. We sought to clarify the contextual interconnections between street trees and mental health outcomes in the local populations. Taking a complex systems approach allows for the consideration of the 'multiple effects and potential trade-offs' of street trees. Systems thinking provides a series of tools specifically designed to consider multiple outcomes, non-linearities, feedback loops and unexpected consequences.

We used a complexity-informed configurative review approach with results illustrated by causal loop diagrams (CLDs). We drew on data from a wide range of settings as represented in the literature, and attempted to abstract relationships sufficiently to produce a generalisable conceptual map or theory. We sought feedback from project partners (subject area experts and municipal and civil society stakeholders in the ULLs) to validate the model.

Instead of focusing on mental health as a singular outcome, we focused on the systems around mental health. First we developed a simplified version of the CLD produced by Wittenborn et al.(2) We then considered 414 studies of street trees and extracted data from 56 key papers. We identified 103 hypothesised causal relationships and extracted data on the cause, outcome and polarity of each relationship. We identified cause-outcome pairs to construct an initial CLD integrated with Wittenborn et al.'s mental health model.

Results

In total we identified 103 hypothesised causal relationships in the system relating to street trees and mental health. Five key relationships were explored in detail.

Key finding 1: Many pathways exist through which street trees may impact mental health. We identified at least 20 pathways (i.e. processes which link cause and outcome) through which trees may have a positive impact on mental health or the determinants of mental health. The pathways include: reductions in local temperature, which may reduce sleep problems, aggression and violence;

reductions in noise which may reduce perceived stress and sleep problems; a range of calming and restorative effects including improvements in cognitive performance reductions, in negative affect, and reductions in mental fatigue; increased sounds and views of nature, which may both reduce perceived stress and improve physical health; improvements in community cohesion which can improve interpersonal relationship quality and impact mental health; and through increased environmental biodiversity which may increase the "good bacteria" living on or in the human body and improve physical health. We also identified a small number of pathways by which street trees may negatively impact mental health, e.g. through pollen causing allergic responses, or through tree vandalism resulting in reduced area attractiveness.

Key finding 2: To impact mental health, tree health is critical. For the positive impacts of street trees on mental health to be realised, the health of street trees is critical. Many of the benefits of street trees are linked to tree canopy size (e.g. cooling effects, noise reduction, shade, etc.), and tree canopy size is partly driven by tree health. Municipal-level variables are in part determined by whether trees are seen as an investment by residents and decision-makers. As people experience the benefits of street trees (not only around mental health, but around aesthetic appeal, increased property values, etc.), support for street trees may increase, potentially justifying additional resource allocation.

Key finding 3: Over time, reinforcing cycles can produce inequities in tree coverage and benefits. Historical differences in street tree coverage can become exacerbated over time, resulting in widening inequities as some neighbourhoods enjoy the benefits of street trees (links 4 and 5, Figure 4) and are able to reinvest in tree health (links 7-9, Figure 4) while others enter a vicious cycle in which street tree benefits are not realised and tree health deteriorates.

Key finding 4: Street trees, and other green infrastructure, face competition for scarce resources. When investments in street trees are low and funds/space are allocated towards more traditional 'grey' infrastructure, well-funded municipal projects (e.g. roadworks) are likely to be successful and gain relative power, enabling them to advocate for additional resources, further reducing resources available for trees. On the other hand, when resources (finances, space) are diverted towards street trees, there may be less investment available for other types of green infrastructure. Given the ambitious tree planting campaigns promised by many politicians,(3) these other types of green infrastructure may become deprioritised.

Key finding 5: Street trees impact residents in ways they do not perceive or are not asked about. In surveys of residents' perceptions of street trees, mental health and determinants of the system around mental health (e.g. stress, crime, sleep) are rarely included in questionnaires. Most studies appear to focus on the impacts of street trees which are clearly observable, e.g. shade, privacy, etc. Some of the benefits of street trees are difficult to perceive at an individual level and are likely under-valued.

Discussion and conclusions

We used a complex systems approach to review and synthesise evidence relating to how street trees interact with the system around mental health, developing a series of causal loop diagrams (CLDs) using evidence of relevance to Europe and China. We suggest that there are at least 20 plausible pathways through which street trees may impact mental health directly and indirectly. However, for these benefits to be realised, the health of street trees is critical. Given reinforcing loops between the determinants of street tree success and the mental health system in general, historical differences in street tree coverage may be exacerbated over time, entrenching low investment, both within the communities themselves but also at the municipal level, producing substantial inequalities in tree

coverage. Street trees often compete with other municipal infrastructure for resources (financial, space) in a 'success to the successful' systems archetype.

Many of the mental health benefits of street trees are less obvious both to researchers and residents and as such may not be considered in decision making. We have explored the complex systems relating street trees to mental health in this report, and conclude that there is a need to build the evidence base to develop a more detailed understanding of *how* street trees are thought to operate within the complex systems that produce health and wellbeing. We suggest systems-thinking approaches could be used to improve our understanding of how street trees relate to mental health.

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ABBREVIATIONS

CLD	Causal Loop Diagrams
MA	Miriam Alvarado
MDD	Major Depressive Disorder
NBS	Nature Based Solutions
ULLs	Urban Living Labs
WP	Work Package

1 INTRODUCTION

1.1 Purpose of the document

The purpose of this document is to report the completed findings of Work Package 4, Task 4.1. The objectives of the task were; first, to take a complexity-informed approach to considering the interconnections between Nature Based Solutions and mental health through a review and synthesis of evidence, and consultation with stakeholders, to provide background, establish knowledge gaps and generate evidence to inform the other tasks and deliverables of WP4 (D4.2-D4.5), as well as the wider project and link directly to the Urban Living Labs (ULLs). The second objective was to reflect on the application of the complexity informed synthesis methodology, and specifically, causal loop diagrams; considering key strengths and limitations of the approach we took. Both the approach used and focus of Task 4.1 was different to that initially proposed, however an amendment request was submitted on December 4th 2020 and approved in January 2020.

Guided by the REGREEN ULLs (European and Chinese site rankings of multiple NBS) we prioritised a focus on street trees and their potential impact on mental health (see section 2 for detail on this process). Street trees are an example of a Nature Based Solution with the potential to provide a range of ecosystem services including climate regulation, air quality regulation and aesthetic and cultural services.(4,5) Interest in the potential of street trees to mitigate the impacts of a changing environment is increasing. As a result, there are now a number of large scale street tree ambitions and strategies.(4,6–8)

Several recent reviews had considered the impacts of street trees in particular and of urban trees more generally.(4,9,10) For example, Salmond et al.(4) reviewed the ecosystem services provided by street trees, with a focus on climate change, air quality and cultural ecosystem services, while Wolf et al.(10) conducted a scoping review around urban trees and human health, with a broad focus around reducing harm (e.g. air pollution), restoring capacities (e.g. attention restoration) and building capacities (e.g. active living). Whilst these reviews highlighted the potential of street trees, they also emphasised the challenges in considering the multiple pathways (i.e. the processes which link cause and outcome) through which street trees are thought to operate, unexpected consequences, and evaluating impact.

We used systems thinking and took a complexity-informed approach, developing causal loop diagrams (CLDs), to understand the role of street trees for mental health outcomes. Systems thinking on this topic is characterised by:

- The use of a series of tools specifically designed to consider multiple outcomes, non-linearity, feedback loops and unexpected consequences.(11,12)
- Offering new insights around the structures of systems - for example, conceptualising ‘mental health’ as a system rather than as an ‘outcome’.

Through the development and analysis of a series of causal loop diagrams (CLDs) using evidence of relevance to Europe and China, we undertook a complexity-informed synthesis which assessed how street trees as a Nature Based Solution (intervention) may interact with the existing complex system around mental health.

Contributors to this report come from WP4 (Wellbeing assessments and valuing benefits of Nature Based Solutions). The report has benefited from the contribution of a wider group of collaborators including representatives from all six REGREEN ULLs.

1.2 Scope of the document

This document details the completed work of WP4, Task 4.1. The content relates to the method and results of the conceptual modelling of the complex systems relating to the contextual interconnections between a type of NBS, street trees, and mental health outcomes in local residents. The conclusions are of relevance to a range of Regreen stakeholders and geographies.

1.3 Structure of the document

This document provides an introduction to the role of street trees, as a form of NBS, and the current evidence which has described their association with mental health. It then describes the methodology used to explore the complex pathways between the provision, presence and maintenance of street trees and mental health systems. The results of developing causal loop diagrams to describe street tree systems are then discussed, focusing on five key linked findings: 1) the many pathways through which street trees may impact mental health; 2) to impact mental health, tree health is critical; 3) how, over time, tree health produces inequities in tree coverage and benefits; 4) the relevance of competition for scarce resources; and 5) street trees impact residents in ways they do not perceive (or are not asked about). The document ends with discussion of the findings and implications for policy and practice.

1.4 Related publications

At the time of submission, two papers relating to content described here are in progress for publication in peer-reviewed journals (one under review, and one in preparation to be submitted).

2 NATURE BASED SOLUTION SELECTION

Cities around the world are facing significant and overlapping challenges around urbanisation, climate and other forms of environmental change, as well as considerable health, well-being and social inequalities. Nature Based Solutions (NBS) are being promoted and adopted as a promising approach to help address many of these interrelated challenges. NBS have been defined as interventions which are "inspired and supported by nature, which are cost-effective, provide simultaneous environmental, social and economic benefits, and to help build resilience."(13) Examples of NBS include greenways, green roofs, and flood management systems using natural features such as bioswales or wetland creation or amenity areas. NBS deliver a range of ecosystem services depending on factors such as their type, location and the geographic, biologic, climatic and socio-cultural context. (13)

Consultation with ULL partners was carried out through the wider REGREEN collaboration in order to gauge interest in, and relevance of, different NBS for the six ULL cities/regions. ULL representatives were asked to complete a table of NBS types, scoring each from 0 (no interest) to 2 (high interest). The scoring of these NBS is presented in Table 2, and clearly indicates street trees as an NBS relevant to all six ULLs, with five scoring them as 'high interest' and one scored as 'some interest'. 'Parks' were the only NBS ranked more highly than street trees.

Table 1: Summary of NBS rankings by the ULLs

			Scoring for interest of ULLs (0-No interest; 1-Some interest; 2-High interest)					
Brief description	Object type	Object category	Paris	Velika Gorica	Aarhus	Shanghai	Beijing	Ningbo
Mainly private space linked to dwellings	Gardens	Balcony	2	1	2	2	1	1
		Private Garden	2	2	2	0	0	1
Mainly public space, but some access restrictions may apply	Parks	Pocket Park	-	2	2	2	2	2
		Park	2	2	2	2	2	2
		Botanical Garden	1	0	2	1	1	1
		Heritage Garden	1	0	1	1	1	1
		Nursery Garden		1	2			1
Civic areas designed primarily for specific amenity uses	Amenity areas	Sports Field	0	1	1	1	0	2
		School Yard	2	2	2	1	0	2
		Playground	2	1	2	1	0	2
		Shared Open Space (Not Green)	0	1	1	1	0	2
Mainly civic areas designed primarily for specific uses (not primarily leisure)	Other public space	Cemeteries	2	1	2	1	0	0
		Allotment	2	2	2	1	0	1
		City Farm	2	2	2	1	0	1
		Urban Beekeeping	-	2	2	-	-	0
		Street Tree	2	2	2	1	2	2
		Cycle Track	1	2	2	1	1	1

Linked to transport and access	Linear features/routes	Footpaths, Including Along Waterways	1	2	2	1	2	1
		Road Verge	1	2	2	1	1	2
		Hedges	-	2	2		-	2
Constructed green and blue space, added to infrastructure	Constructed GBS on top of infrastructure	Green Roof	2	2	2	0	1	1
		Green Wall	2	2	2	0	0	1
		Roof Garden	0	2	2	0	0	1
		Bioswale	2	2	2	0	0	2
		Pergola	0	1	1	0	0	2
Infrastructure designed to incorporate some GBS components	Hybrid GBS	Permeable Paving	1	2	2	1	0	1
		Permeable Walkway	1	2	2	1	0	1
		Permeable Roadway	1	1	2	1	0	0
		Permeable Parking	1	2	2	1	0	1
Blue space features	Wetlands	Constructed Wetland	2	2	2	2	2	2
		River/Stream	2	1	2	2	0	2
		Canal	1	1	1	2	0	2
		Pond	2	1	2	2	0	2
		Lake	1	1	2	2	0	2
		Reservoir	0	0	2	2	0	2
		Estuary/Tidal River	0	0	0	1	0	2
		Sea	0	0	2	1	0	2
Other vegetated features without specified use, often on private land	Other vegetated urban areas	Urban Forest	2	1	2	1	2	1
		Grass/Shrub	2	1	2	1	2	1
		Heathland	2	0	1	1	0	1
		Other Semi-Natural Vegetation	2	1	2	1	1	1
		Arable Land	-	2	2	-	-	0

Street trees are an example of a NBS with the potential to reduce the heat island effect, improve air quality, increase carbon sequestration, and improve the quality of living environments. (4,5) Interest in the potential of street trees to help adapt to and mitigate the consequences of environmental change and contribute to better health and wellbeing outcomes is growing. As a consequence many local and national campaigns have been launched with the aim of planting large numbers of street trees. (3,4,6–8)

Given this context, and the high ranking by ULLs, we aimed to review and synthesise evidence relating to street trees, a key form of NBS, and their contribution to health and well-being outcomes in order to establish knowledge gaps and generate evidence to inform what works, where and why.

3 BACKGROUND

3.1 Street trees

We define street trees as trees growing alongside public roads, regardless of whether they are managed publicly or privately. Street trees are a type of a NBS with the potential to provide a range of ecosystem services including climate and air quality regulation, and aesthetic and cultural services.(4,5)

Whilst several reviews have highlighted the potential of street trees (4,9,10), few syntheses or conceptual models have sought to demonstrate *how* street trees operate within the systems they are situated, nor do they describe the conditions in which impacts do or do not come about. Thus, limiting understanding of how best to use street trees for social benefit. Being able to simultaneously convey the multiple mechanisms through which street trees may operate would allow a more nuanced approach to effect estimation, reducing the mis-estimation of any single pathway,(14) and enabling more targeted research and hypothesis testing to produce stronger causal claims.(14,15). Salmond et al. concluded that the impacts of street trees must be considered holistically: "Current research in this field often emphasises a singular benefit and direct planners towards a single-variable optimisation strategy. This becomes problematic when a single-variable intervention offers different outcomes and has multiple effects and potential trade-offs."(4)

3.2 A complexity informed approach to understanding street trees

Many of the societal and environmental challenges that we face require large-scale, population-level interventions; from tackling the obesity crisis to addressing climate change. However, evaluating and synthesising evidence around these kinds of interventions is not straightforward, particularly because they are introduced in real-world settings beyond the controlled context of a lab.(11,16)

These kind of interventions are often (perhaps always) introduced into 'complex systems', which are defined as systems demonstrating emergence, feedback and adaptation.(11,17) Consequently, and as noted above, evaluations of these large-scale population-level interventions need to acknowledge the multiple and often non-linear ways in which these interventions may impact the system(s) and be impacted by them.(17,18) Rutter et al. elaborate: "A shift in thinking is required, away from simple, linear, causal models, to consideration of the ways in which processes and outcomes at all points within a system drive change. Instead of asking whether an intervention works to fix a problem, researchers should aim to identify if and how it contributes to reshaping a system in favourable ways." (11)

Taking a complex systems approach may provide one way forward in addressing Salmond et al.'s (4) call to consider the 'multiple effects and potential trade-offs' of street trees. Systems thinking provides a series of tools specifically designed to consider multiple outcomes, non-linearity, feedback loops and unexpected consequences.(11,12) Further, such complexity informed approaches enable the explicit integration and consideration of wider structures (e.g. the system around mental health).(19) In this analysis, we focused on integrating a multifaceted understanding of the impacts and influences of street trees within a systemic understanding of mental health. Here, we follow Donella Meadows in defining a system as "a set of things […] interconnected in such a way that they produce their own pattern of behaviour over time"(20).

While there are relatively few systemic representations of mental health (21), a 2019 review of "Complex Systems Approaches to Understand Drivers of Mental Health" identified a model produced by Wittenborn et al. as an "excellent example of how complex systems approaches can leverage research across disciplines (e.g., neurobiology, psychology, social epidemiology) regarding the structure and function of drivers of mental health conditions"(21).

Wittenborn et al. (2) took a complexity-informed approach to synthesise evidence around the determinants of major depressive disorder (MDD) and social, environmental, cognitive and biological systems. The authors drew on empirical findings from 594 relevant publications, explicitly linking 46 papers to specific causal arrows to develop their CLD, which they then validated with five relevant experts.

While Wittenborn et al.'s (2) model focused on major depressive disorder, it provides a useful proxy for considering mental health more broadly. Many of the pathways highlighted (e.g. economic status and stress, physical health and physical inactivity etc.) contribute to broader conceptions of mental health. Given our interest in exploring how street trees may impact mental health at multiple levels (e.g. physiological, social/cultural), and the relative scarcity of systemic representations of mental health, we accepted Wittenborn et al.'s model as a useful and pragmatic starting point. We define the system boundary (e.g. the "set of elements that comprise a system of interest to make research on that system tractable")(22) on the basis of Wittenborn et al.'s established model. Within this system, we conceptualise street trees as an exogenous intervention which may interact with various aspects of the mental health system.

3.3 Street trees and mental health outcomes

The burden of disease around mental health is high (23,24) and projected to increase.(25) Finding population level strategies to avoid, reduce and mitigate poor mental health is a key priority globally. (26) NBS are one of the contributory options being considered to address the causes and consequences of poor mental health in urban areas. Continuing with the systems thinking lens, we conceptualise 'mental health' also as a complex adaptive system comprised of multiple simultaneous interrelated determinants and consequences (e.g. socioeconomic status, physical health, stress, sleep problems, etc.) which contribute to states of mental wellbeing or mental illness. Mental wellbeing and mental health are defined here as distinct but related states, with mental wellbeing a contributory factor to mental health (the absence or presence of mental illness). (27)

While links between nature and mental health, (14,28) urban trees and mental health,(10,29) and overall benefits of street trees (4,9) have been documented in a number of reviews, the links between street trees and mental health remain less clear. However, street trees may have an important role to play, especially considering the burden of mental health is greater in urban areas: "Studies have shown that the risk for serious mental illness is generally higher in cities compared to rural areas ... Social isolation and discrimination as well as poverty in the neighbourhood contribute to the mental health burden while little is known about specific interactions between such factors and the built environment." (30)

3.4 Objective of the work

The primary objective of this study was to take a complexity-informed approach to considering the interconnections between street trees and mental health. As such, we do not focus on summarising a list of the impacts of street trees on health (see Roy et al. (29) for example), but aim to identify novel

systemic insights and identify what actions may contribute to reshaping the systems related to street trees in favourable ways.

Our second objective was to reflect on the application of the complexity informed synthesis methodology, and specifically, causal loop diagrams; considering key strengths and limitations of the approach we took.

4 METHODS

To address our primary research question - *In what ways may street trees impact the systems around mental health?* – we used a complexity-informed configurative review approach with results illustrated by causal loop diagrams. (31) Table 2 gives an overview of the four-stage approach we took.(12,20) We summarize each step briefly here and in more detail in the subsections that follow.

Table 2: Summary of study methods

Stage	Description of the process	Output
1	Identifying studies based on existing reviews of street tree impacts	Studies for inclusion
2	Extracting data on causal relationships	Data extraction sheet
3	Integrating NBS intervention within system(s) around mental health • Identify linkages • Close loops by introducing additional causal linkages based on background knowledge • Validate CLD with street tree experts and local stakeholders	Integrated CLD
4	Analysing the integrated CLD • Draw on systems archetypes • Seek systemic insights • Validate insights with street tree experts and local stakeholders	Systemic insights and simplified high-level CLDs

First, we conducted a complexity-informed configurative review which allowed us cast a wide net for a diverse range of evidence around street trees, incorporating literature from sociological, urban planning, economic, environmental and health perspectives.

Second, we extracted data from the studies identified through this review, identifying illustrative excerpts for each hypothesized causal relationship to keep a close link between the data extraction and the original concepts represented in the literature.

Third, we used these data as building blocks to develop a detailed causal loop diagram. Causal loop diagrams can be used as tools to aid and inform policymakers about the complexities of addressing environment and health issues. (32) They show in pictorial form how different factors (or nodes) interact to lead to changes in systems, resulting in given outcomes. They have been used in the construction of models of systems, but here we focus on their use as a communication tool in and of themselves and in summarising a wide literature.

Fourth, after developing the hyper-detailed CLD, we engaged in an iterative process of abstraction, validation with experts and refinement. We abstracted the CLDs in a manner not dissimilar from how

an inductive qualitative analysis may progress, moving from detailed codes to higher levels themes and identifying possible relationships between themes. We continued to read and re-read the extracts to ensure the abstracted concepts and relationships reflected the original data. We also considered whether systems archetypes (e.g. established patterns of connected feedback loops within CLDs) may help explain or further abstract from the detailed CLD to a higher-level analysis (in a similar manner to how a qualitative researcher may use an established theory to further explore relationships between codes, subthemes and themes. Throughout this step, we sought feedback from project partners (subject area experts and municipal and civil society stakeholders in ULLs) to validate the model.

4.1 Stage 1: Identifying studies based on existing reviews of street tree impacts

We followed in the tradition of configurative(31) and conceptual reviews(33) and adopted a pragmatic non-systematic review approach, as has been used elsewhere.(32,34) While we recognise the value of systematic reviews (e.g. around summarising the literature on particular interventions to improve given health outcomes), given our task here was to identify different pathways for street trees to impact on mental health and mental wellbeing, this approach was considered to be sufficiently robust to fit the purposes of the REGREEN project more widely.

We drew on several reviews of street trees(4,9,10) to iteratively identify empirical studies for inclusion, using a backward and forward chaining approach.(35) This was a pragmatic decision, intended to enable the efficient identification of relevant studies. We also consulted with several relevant experts for additional references. Using this approach, we supplemented our initial body of literature on street trees by conducting iterative targeted searches for studies around specific second-order relationships, or causal hypotheses that may have linked one of impacts of streets trees with one of the factors in the base model of mental health determinants and impacts that we used(12) (see next section for details).

We included empirical studies with a focus on urban environments. We excluded modelled or simulation studies, as well as opinion-based or anecdotal papers without an empirical basis, such as editorials, commentaries and letters to the editor. Otherwise, we did not restrict by study type. At the point at which several studies had been identified to provide evidence for a given causal relationship, we focused attention on other causal relationships rather than amassing additional evidence on the same set of relationships.

4.2 Stage 2: Extracting data on causal relationships

We employed an iterative approach to extracting data. Given our focus on a very broad range of hypothesised causal relationships (rather than on quality of evidence for a narrower set of relationships, as in a traditional systematic review), we did not assess the quality or risk of bias of individual studies. This was a pragmatic decision, given the wide range of relationships considered, the variety of disciplines represented and the related challenges in developing consistent and explicit criteria. As such, the results presented here should be interpreted as causal hypotheses, rather than validated relationships.

For each included study, we extracted data on:

- Cause
- Effect
- Polarity [+/-] (i.e. the direction of relationships, positive or negative)
- Delayed process [y/n] (i.e. whether processes or outcomes take time to manifest)
- Evidence type (empirical, review finding, study team assumption)
- Human population (adults/children, etc.)
- Tree population (deciduous/coniferous, etc.)

Data was extracted using a standardised Excel template(36) by MA. We did not extract data on effect size, variability, statistical tests, etc. Instead, we aimed to capture a wide range of empirical relationships, as has been done in previous complexity-informed theoretical reviews.(34)

For key relationships with a large body of evidence we drew on synthesised review findings to summarise the evidence. For a limited number of relationships without sufficient empirical evidence it was necessary to make assumptions (e.g. we assumed that tree vandalism reduces the attractiveness of a neighborhood, although we did not specifically find evidence on this). These relationships are clearly tagged as 'study team assumption' within the database.

Evidence relating to mental health

Instead of focusing on mental health as a singular outcome, we began by focusing on the systems around mental health. First we developed a simplified version of the CLD produced by Wittenborn et al.

choosing to primarily focus on the social and environmental dimensions.(12) Additionally, we collapsed some of the cognitive and biological dimensions as described by Wittenborn et al. where necessary to explain pathways in the street tree system. We saved this simplified model in an Excel sheet, in which each row corresponded to a causal relationship and included fields such as "cause," "outcome," "polarity"(+/-) and "delay" (yes/no). In total we reproduced the 13 hypothesised causal relationships from Wittenborn et al.'s model.

Evidence relating to street trees

In total, we considered 414 studies of street trees and extracted data from 56 key papers. We identified 103 hypothesised causal relationships and extracted data on the cause and outcome, as well as the polarity of each relationship in an Excel sheet. We also included fields for 'description,' in which we briefly summarised the evidence for the relationship in a few sentences, and a field for 'references' in which we copied URL links to the underlying papers for each relationships (e.g. in some cases multiple references contributed to one link, and in other instances the same reference contributed to multiple links). We extracted data on the human population considered in each paper as well as on the tree population. For each hypothesised causal relationship, a second member of the study team reviewed the evidence associated with that link and corroborated the relevant data extraction, suggesting revisions or clarifications which were then resolved by the whole study team.

4.3 Stage 3: Integrating NBS intervention within system(s) around mental health

Developing the CLD

We then used each of the identified hypothesised causal relationships to construct an initial CLD integrated with Wittenborn et al.'s(2) model (for a combined total of 117 hypothesised causal relationships).

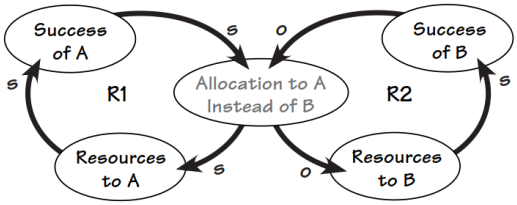
CLDs are represented through standardised notation and can be used to convey hypothesised causal relationships, polarity, delays, and direction of feedback loops. Loops may be 'balancing' (self-regulating through balanced positive and negative relationships) or 'reinforcing' (i.e. virtuous or vicious cycles). While logic models, conceptual maps and other diagramming tools may also be used to summarise hypothesised causal relationships, CLDs are specifically intended to highlight and explore aspects of complexity by capturing feedback loops, delays, and multiple non-linear impacts.(12,20) Generic systems archetypes have been identified which may aid in the analysis of CLDs (see Box 1 for details).(19)

We used Kumu (www.Kumu.io), a freely available online platform to produce the CLD. Kumu is designed to be used for stakeholder mapping, systems mapping, social network mapping, concept mapping, etc. and includes specific templates (e.g. a CLD template). Kumu enables users to create CLDs directly in an online interface, by clicking to add individual elements, connections and loops. We imported our Excel sheet into Kumu's CLD template, and re-arranged elements to clearly highlight various loops and themes on the map. We used Kumu's functionality to label loops and important thematic groupings.

Box 1: Generic CLD Systems Archetypes

There are a number of CLD archetypes (patterns which have been observed across many different kinds of systems) which may enable the identification of deeper structural patterns within a system.[13,14] For example, one key archetype is the 'Success to the Successful' archetype (see Figure 1). Briefly, this describes a system in which, "if one person or group (A) is given more resources, it has a higher likelihood of succeeding than B […] This initial success justifies devoting more resources.."[13]

Figure 1: Success to the Successful Archetype, reproduced from Kim 1994



Over time, individuals or groups within this structure are likely to develop divergent levels of success, and it may seem that the success of one person or group (A) is due to implicit characteristics, or even measurable performance indicators. However, that is misleading, as this archetype highlights that divergent outcomes may be driven by completely by differences in initial resource allocation.

Another implication of this archetype is that individuals or groups are in competition with one another, in a zero-sum scenario. Accordingly, one way to change this archetype is to "identify goals or objectives that define success at a level higher than the individual players A and B," and "find ways to make teams collaborators rather than competitors."[13]

There are a number of other systems archetypes which have been described in detail elsewhere.[13,14]

4.4 Stage 4. Analysing the integrated CLD

We produced simplified CLDs at a higher level of abstraction to summarise key dynamics (e.g. going from 117 relationships to 9 in the most parsimonious summary). We also integrated one key generic systems archetype ("Success to the Successful") at the simplified CLD level of analysis and considered whether other archetypes may be of use in uncovering systemic structures. Kim has summarized eight key systems archetypes, which are simple combinations of several feedback loops which have been found to exist in many different kinds of systems.(19) We considered each of these in turn, and concluded that the "Success to the Successful" archetype helped us to summarize and explain a dynamic that was well-evidence in the literature around resources for trees (see

).

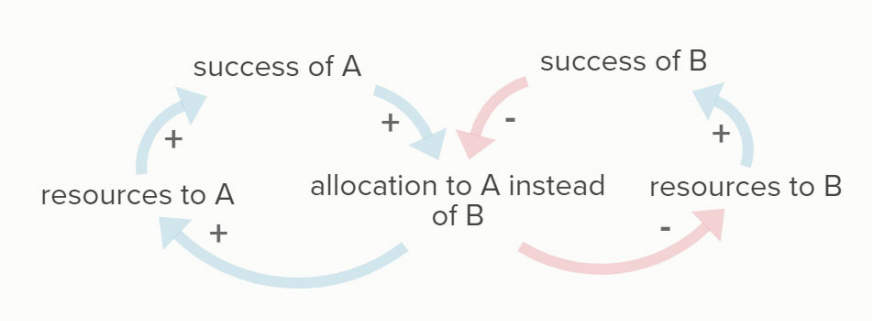


Figure 2: 'Success to the Successful' system archetype, reproduced from Kim 1994 (19)

We then shared the CLD with three groups of municipal-level stakeholders (REGREEN project partners in Aarhus, Denmark, Paris region, France, and Velika Gorica, Croatia) during online workshop meetings, with copies emailed ahead of the meeting for preparatory review. In these meetings, the stakeholders provided overall reflections and commented on the feasibility of the preliminary findings. These were used to make additional revisions to the model. Finally, we developed an online presentation to allow users to click through the CLD in a guided fashion, in an attempt to make what could be an overwhelming diagram more digestible.

While this has been presented as a linear process, in reality we iterated between steps two and three. Following CLD best practice, we aimed to produce a parsimonious model while maintaining important levels of detail.(21) We were guided in these decisions by revisiting our research question, and dropped causal relationships with no clear (2^{nd} or 3^{rd} order) link to the mental health system. For example, while street trees may reduce stormwater runoff and thus reduce flash flooding, and flood-related risk may increase stress stimuli, we did not deem this link to be strong enough or impactful enough to represent in the final CLD. These decisions are inherently subjective, and highlight the importance of viewing 'finalised' CLDs as a representation of one group's mental model, rather than of an objective reality.

5 RESULTS

The simplified version of Wittenborn et al's (2) model of the determinants of mental health focusing on the social and environmental dimensions is shown in Figure 3Some of the cognitive and biological dimensions as described by Wittenborn et al. are also included where relevant.

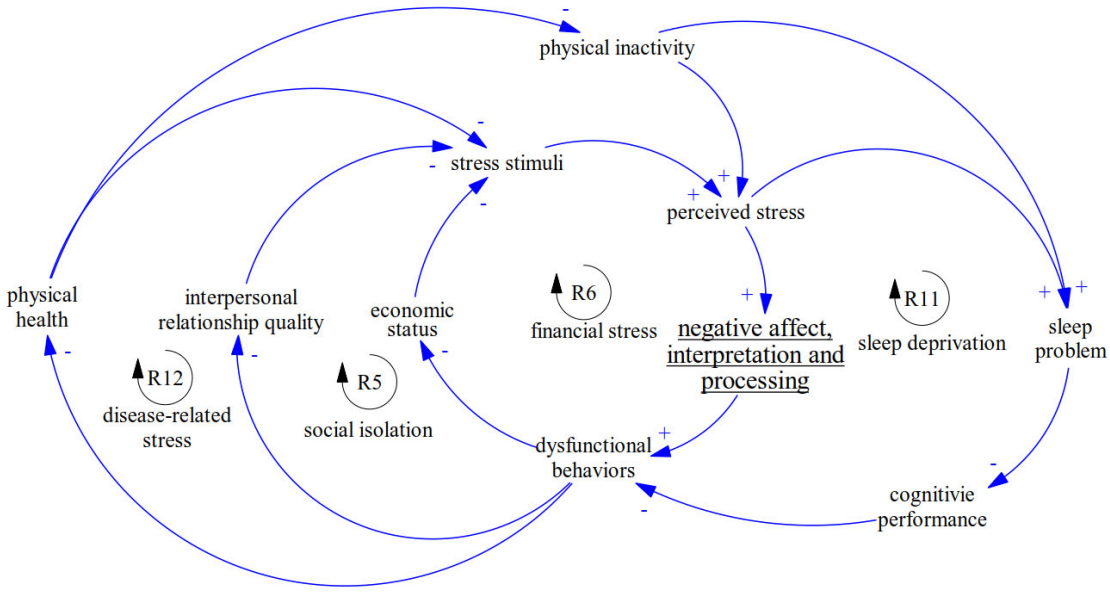


Figure 3: Simplified CLD from Wittenborn et al focusing on social and environmental reinforcing loops

Note: Sustained negative affect may be diagnosed as major depressive disorder, the mental health outcome of focus in Wittenborn's model.

We used this simplified model as the basis for the development of the street tree CLD. The full CLD is available online (https://kumu.io/miriamalvarado/street-trees-mental-health#untitled-map).

In the following sections, we explore key relationships.

5.1 Key finding 1: Many pathways exist through which street trees may impact mental health

From the reviewed evidence, we identified at least 20 pathways through which trees may have a positive impact on mental health or the determinants of mental health. This list is not exhaustive but highlights the diversity of ways in which street trees may impact mental health.

The pathways include: a) reductions in local temperature, which may reduce sleep problems (37), b) reduce heat-related cognitive underperformance (38), c) reduce heat stress-related morbidity and mortality (10), and d) reduce heat-stress related dysfunctional behaviours (e.g. aggression and violence)(28); reductions in noise which may e) reduce perceive stress(39) and f) reduce sleep problems; a range of calming and restorative effects derived from the tree canopy and street tree stock, including g) improvements in cognitive performance (40), h) reductions in negative affect (10,15,41,42), and i) reductions in mental fatigue and related dysfunctional behaviours(43); j) reductions in crime and related stress stimuli (40,44); k) reductions in sleep problems(45); l) increased sounds and m) views of nature, which may both reduce perceived stress(28) and n) improve physical

health (e.g. surgery recovery)(46); improvement in air pollution which o) improves physical health,(10,47) which impacts mental health and p) improves improve cognitive performance(48); q) increased walkability which improves physical activity(49,50); r) reductions in ultraviolet radiation which impacts physical health(10); s) improvements in community cohesion which can improve interpersonal relationship quality and impact mental health(15,28,51); and t) through increased environmental biodiversity which may increase the "good bacteria" living on or in the human body (28) and improve physical health.

Street trees may also have a negative impact on mental health. For example, some species of trees may increase pollen exposure, increasing allergies with a negative impact on mental health.(10) Low-growing tree canopies may block visibility and increase crime, increasing stress stimuli with an impact on mental health.(44) Residents may find that trees block sunlight or desirable views, that trees damage sidewalks and reduce walkability when sidewalks are not well-maintained, and that tree limb or tree falls pose a risk to damage and human life, especially in storm-prone regions. However, the majority of these disservices can be addressed with appropriate tree management programs (i.e. planting appropriate species selection to reduce pollen, proactive pruning to reduce the risk of tree limb falls, etc.)(52)

5.2 Key finding 2: To impact mental health, tree health is critical

For the positive impacts of street trees on mental health to be realised, the health of street trees is critical (see Figure 4).

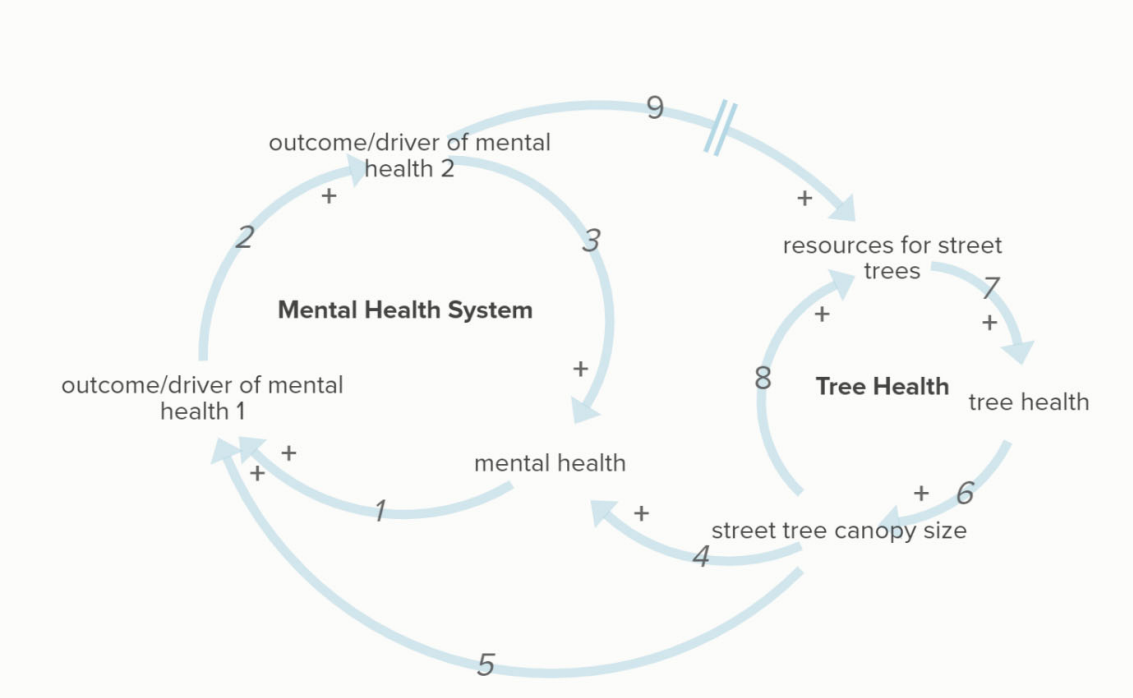


Figure 4: Tree health is critical for street trees to impact mental health

Many of the benefits of street trees are linked to tree canopy size (e.g. cooling effects, noise reduction, shade, etc.), and tree canopy size is partly determined by tree health (link 6). Stressed trees do not grow very well or quickly, and often have shorter lifespans. Unlike trees in natural settings, street trees tend to require support to thrive in otherwise challenging urban conditions and tree health is determined by appropriate tree management and adequate resources for management (link 7).

These municipal-level variables are in turn, and in part, determined by whether trees are seen as an investment by residents and decision-makers. As people experience the benefits of street trees (not only around mental health, but around aesthetic appeal, increased property values, etc.), support for street trees may increase, potentially justifying additional resource allocation (link 8). Finally, determinants of mental health (e.g. community cohesion, socioeconomic status, crime and street tree vandalism) may impact resources for trees, albeit perhaps over a longer time horizon (link 9). As Figure 4 illustrates, these two reinforcing loops are interconnected. Improvements in tree health may lead to improvements in mental health and vice versa, as the two loops reinforce each other.

However, reinforcing loops can also produce vicious cycles. For example, where resources for street trees are low, tree health is likely to suffer (link 7), resulting in fewer trees and smaller canopies (link 6). The full benefits of street trees are unlikely to be realised (links 4, 8 and 9). We found some evidence to support this negative cycle. For example, Pauleit et al. (53) found that “in countries where the maximum level of vandalised trees is high, smaller trees are usually planted. Thus, there seems to be a relation between the overall level of investment in new tree planting and the level of vandalism.” In the UK, residents cited not wanting trees because “they would be destroyed by vandals, wasting council tax payers' money for no benefit.”(54) In this setting, a vicious reinforcing loop may have led to low investments in street trees, with residents unlikely to perceive many benefits of street trees, further eroding future investments.

5.3 Key finding 3: Over time, reinforcing cycles can produce inequities in tree coverage and benefits.

These reinforcing loops also highlight that historical differences in street tree coverage can become exacerbated over time, resulting in widening inequities as some neighbourhoods enjoy the benefits of street trees (links 4 and 5) and are able to reinvest in tree health (links 7-9) while others enter a reinforcing cycle in which street tree benefits are not realised and tree health deteriorates.

Studies have found evidence of marked differences in street tree coverage by race and income groups,(55,56) and efforts to increase the number of street trees in the US have been criticised for exacerbating racial inequalities in street tree coverage.(8,57,58) More advantaged neighbourhoods may be able to advocate more effectively for additional street trees and may be in a better position to take advantage of incentives to plant street trees.

Finding ways to increase resources for trees which are not dependent on past success within municipal areas (e.g. links 8 and 9) will be essential in encouraging a more equitable distribution of street tree coverage.

5.4 Key finding 4: Street trees, and other green infrastructure, face competition for scarce resources

We built on the model presented in **Error! Reference source not found.** by adding two components: other municipal investments and other municipal infrastructure (e.g. roads, other types of green infrastructure, etc.) (see Figure 5).

When investments in street trees are low and funds/space are allocated towards more traditional 'grey' infrastructure, these well-funded municipal projects (e.g. roadworks) are likely to be successful and gain relative power (link 11), enabling them to advocate for additional resources (link 12), further reducing resources available for trees (link 7).

On the other hand, when resources (finances, space) are diverted towards street trees, there may be less investment available for other types of green infrastructure. Given the ambitious tree planting campaigns promised by many politicians,(3) these other types of green infrastructure may become deprioritised.Suboptimal levels of different types of NBS may result from a polarised focus on particular options. It may be that a more balanced portfolio of NBS may lead to greater benefits to society as a whole.

Competition for resources and space resulted in a potential success to the successful cycle between road maintenance experts and tree coordinators (**Error! Reference source not found.**): "Whose %$#&^idea was it to make trees assets?" This came from a road maintenance coordinator confronted with the responsibility to consult with the trees coordinator before resurfacing a Council car park where trees had dislodged 'his' kerbs. Herein is evidence of the importance of public trees being part of the asset portfolio. (Hewett) (52)

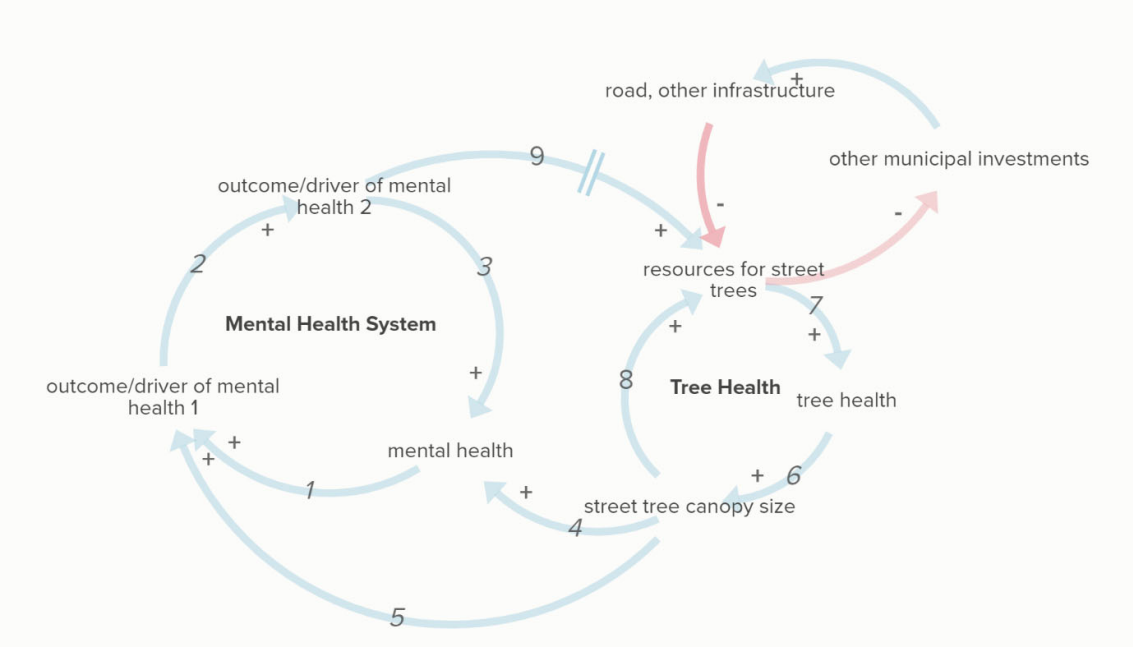


Figure 5: Success to the successful archetype

In the competition for resources, trees often lose: “Professional conflict between arboriculturists and highway engineers is common […] The result is usually the separation of the space below the surface into a zone where engineering design parameters must be achieved regardless of the tree, and a (much smaller) zone in which the arboriculturist is allowed to specify his/her preferred conditions. As a result the choice of species is restricted to trees of small stature and considerable drought tolerance.”(59)

Many of the benefits associated with larger trees fail to be realised, apparently justifying the under-investment in trees (links 8 and 9) and closing the reinforcing vicious cycle: “…limited growing space in cities is responsible for increased planting of smaller, shorter-lived trees that provide fewer benefits compared to larger trees.”(39) These examples represent a classic ‘success to the successful’ system.

5.5 Key finding 5: Street trees impact residents in ways they do not perceive or are not asked about

Finally, in surveys of residents’ perceptions of street trees, mental health and determinants of the system around mental health (e.g. stress, crime, sleep) are rarely included in questionnaires or explored qualitatively.(60–63) Researchers themselves may not be aware of the wide range of potential benefits of street trees. Several exceptions include Heimlich et al.’s inclusion of “they help make a neighborhood feel safe” (ranked last in list of benefits by participants)(64) and Lohr et al.’s (65) inclusion of “trees in cities help people feel calmer” (ranked 2nd in list of benefits by participants).

However, most studies appear to focus on the impacts of street trees which are clearly observable, e.g. shade, privacy, etc. Some of the benefits of street trees are difficult to perceive at an individual level and are likely under-valued (links 8 and 9). Finally, the lack of more exploratory work on the benefits of street trees for mental health may have contributed to limited quantitative evidence focusing on a narrow set of outcomes and pathways.

6 DISCUSSION

Our two objectives were, first, to review literature around street trees and identify a range of ways in which street trees may impact mental health and the determinants of mental health. We sought to identify what actions may contribute to shaping the systems related to street trees. Our second objective was to consider the utility and applicability of using a complexity-informed approach to consider NBS.

6.1 Street trees and mental health

We suggest that there are at least 20 plausible pathways through which street trees may impact mental health directly and indirectly. However, for these benefits to be realised, the health of street trees is critical. Given reinforcing loops between the determinants of street tree success and the mental health system in general, historical differences in street tree coverage may be exacerbated over time, entrenching low investment, both within the communities themselves but also at the municipal level, producing substantial inequalities in tree coverage. Street trees often compete with other municipal infrastructure for resources (financial, space) in a 'success to the successful' systems archetype. Finally, many of the mental health benefits of street trees are less obvious both to researchers and residents and as such may not be considered in decision making.

Whilst many studies have considered and identified the impacts of urban trees(10,29) and street trees in particular (4,9), this is the first study that we are aware of to use a complexity-informed approach to investigate the influence of wider systems. We suggest that there is an added value in taking this approach. For example, our identification of a 'success to the successful' system structure allowed us to draw on relevant guidance which may help identify strategies to address challenges: "A way to break out of the 'Success to the Successful' archetype is to get rid of its competitive structure and find ways to make teams collaborators rather than competitors […] managing a 'success to the successful' situation requires looking at it from a more macro level and asking ourselves 'what is the larger goal within which the situation is embedded?' […] Without the guidance of a larger goal, the structure will continue to dictate your actions."(19). While there have been calls for improved coordination between municipal sub-departments to improve tree management, perhaps an even more fundamental change is necessary (e.g. the larger goal of creating liveable, sustainable, healthy cities).

A case study in Sydney provides an example of how a shift towards a larger goal may have a substantial impact on street tree health.(52) In the lead-up to the 2000 Olympics, the city invested in capital works (including tree planting programs) to beautify the city. Around the same time, several administrative units were amalgamated, leading to a larger city budget and an increase in municipal personnel. The city hired a team of six professional arboriculturists, who revised tree management policies and led a tree development and maintenance program. Municipal resources for trees were sustained after the Olympics, going from $450,000 in 1999 to $3.6 million in 2009. Together, these changes substantially increased the street tree stock: "Within a 10-year period, the City local government area has almost tripled, and the tree population has increased tenfold. Human resources and financial budgets have been increased to manage this change, and to ensure that the City undertakes best practice tree management". (48) These investments also improved residents' perception of these trees, with complaints about trees dropping dramatically despite an increase in the number of trees overall.(52)

While the Sydney case highlights the transformative change that is possible when a larger shared goal is introduced, it also represents a unique, high-profile scenario (the lead-up to the Olympics and the rapid growth of the city administration). A large increase in available resources altered the system

structure, diminishing the competition between municipal sub-departments. The extent to which adopting a larger shared goal and breaking this cycle is feasible in the absence of such a large shift in resources is unclear. Potentially, climate change and the need for cities to adapt to increasing climate-related threats may provide an impetus to adopt these larger shared goals.

6.1.1 Strength and limitations of the review

This study aimed to use an innovative CLD method to synthesise conceptual evidence relating to many components of a complex system. As such we intentionally focused our efforts on incorporating a wide range of evidence. We did not exclude empirical studies on the basis of study design (e.g. randomised control trial, longitudinal, cross-sectional, etc.), because doing so may have biased the relationships identified (e.g. some relationships are easier to assess using a particular study design). Instead, we took an inclusive approach. We linked each hypothesised causal relationship with excerpts from key studies and associated references to increase transparency. We partially accounted for context by capturing elements which vary across settings (e.g. temperature, residents' perceptions of street trees, etc.).

Given our interest in generating complexity-informed hypotheses, we prioritised drawing on a large and diverse evidence base over producing a standardised quality assessment of included studies. As a result, we do not make causal claims but instead present causal hypotheses for further refinement and testing.

However, we faced several challenges. We were not able to represent differences across subgroups (e.g. amongst people, between children/adults, or amongst trees, between deciduous/coniferous) in our final CLD, although we and our stakeholders recognised that these are important. Moreover, the choice and implications of different tree species vary considerably with context (e.g. temperature, water availability, local climate, etc.). Instead of trying to tease apart how different species and management decisions operate in different contexts, we included a broad category "appropriate tree planting and maintenance activities," to acknowledge the importance of these decisions while accommodating contextual differences. Both these limitations to our CLD show that while systems thinking approaches can be highly effective in mapping complexity, they nonetheless still can only represent a simplified model within particular boundaries to be readable and usable tools. Finally, most of the evidence considered comes from North America, Europe and Australia and it would be important to integrate evidence from a wider range of settings in the future.

6.2 The utility and applicability of using a complexity-informed approach

We outlined the detailed steps that we took in applying a complexity-informed approach to evidence synthesis. We focused on the nonlinearity and feedback loops aspects of complexity and used causal loop diagrams as a tool to visualise these aspects of systems thinking. This approach forced us to consider, up-front, the background system within which the intervention of interest operated.(66) This fundamentally changed the kind of evidence that we sought and the kinds of causal hypotheses that we developed. We found that this approach helped us to bring together diverse and multi-disciplinary findings and identify systemic structures at a higher level of abstraction.

A motivating factor for the approach we took was to assess whether using a complexity-informed approach would add value to the more linear summaries of impact represented in existing reviews. In reflecting on the insights we developed in the evidence synthesis, few would be new to subject area experts, and several have been highlighted in previous reviews(4,9,10) (e.g. there are many pathways through which street trees may impact mental health). However, using CLDs did enable us to illustrate and perhaps 'bring together' the evidence for several key insights which have been alluded to in

previous reviews but not clearly evidenced. The use of the CLD, and especially the abstraction to a simpler CLD combined with the integration of a systems archetype, helped us to illustrate these high-level insights in order to 'tell the story' to those who are not subject area experts. The use of these CLDs also changed our understanding of the intervention of interest in profound and unexpected ways, and helped us to develop more sophisticated hypotheses.

For the early stage evaluation we began with the underlying system (what Hawe refers to as "the background")(66) and then considered how the intervention may impact the system, rather than creating a linear narrative starting with the intervention and ending with the outcome of interest.(67–69) We suggest that this approach is more likely to lead to the consideration of unexpected and non-linear effects. A similar approach could be taken to explore any exogenous intervention though to impact a complex adaptive system. Finally, our use of Wittenborn et al.'s model highlights the value of developing and publishing these types of complexity-informed syntheses which can be built on in future projects.

6.2.1 Strengths and limitations of using a complexity-informed approach

There were a number of strengths of using CLDs to produce a complexity-informed evidence synthesis and evaluation framework. First, we found that the process of developing and refining CLDs facilitated transdisciplinary research,(70) and translation from theory/evidence to implementation. It necessitated input from a multidisciplinary team, and provided a shared mental model for contributors with different backgrounds and perspective. Discussions with ULLs indicated the potential utility of this approach for communicating the multiple values of NBS with their own colleagues and stakeholders. The final CLDs successfully blended insights and evidence from across disciplines, and benefitted from the input from ULL partners.

Second, our use of CLDs helped us to identify additional causal hypotheses. For example, when deciding whether to include a connection between various elements in the CLD, such as noise and cognitive abilities or heat stress and violence, we conducted targeted literature searches and identified studies which we would have missed if we had relied exclusively on the intervention-focused literature. These second-order impacts may still be important pathways to account for in any holistic model.

Third, we benefitted from being able to identify a causal loop diagram depiction of the underlying system, even if the model wasn't a perfect fit (e.g. it was focused on major depressive disorder, whereas we took a broader conceptualisation of mental health/illness). In the absence of finding a complexity-informed summary of the underlying system "ready-to-go," we would have had to do quite a bit of additional work to develop something similar.

We also faced a number of challenges. First, a risk in systems thinking approaches is that insights may become 'untethered' from empirical data.(21) We aimed to maintain the links between empirical studies and the causal relationships we hypothesised on their basis. In Kumu, users can click on any connection to read a summary description of the evidence, review relevant excerpts from references, and click on hyperlinks to the original empirical studies themselves. This transparency and 'closeness' between the hypothesised causal relationships and the data were time-consuming, but represent our attempt to ensure that the insights we developed were grounded in evidence.

Second, the synthesis of relationships from studies conducted in a variety of settings may result in the loss of contextual richness and knowledge. This is an inherent limitation of many forms of synthesis and conceptual modelling, including the development of CLDs. We sought feedback from stakeholders in three cities to ground our CLDs in real-life settings. We aimed to reflect some aspects of context

(e.g. temperature, latitude, residents' perceptions), but we were not able to capture many aspects which may have been important. Policymakers are cautioned to review source references in detail for key components of the map and assess to what extent the evidence base is transferrable to any particular setting. There are also questions regarding how transferable these results, relating to street trees, are to other forms of NBS.

Third, it was challenging to decide how to label elements, and specifically when to aggregate several closely related concepts versus when to preserve nuanced differences. We were guided by our research questions, and made decisions by discussion and consensus, but note that this is an inherently subjective process.

Fourth, we did not appraise the quality of individual studies, given the aims and purpose of this evidence synthesis and our priority on breadth as a prerequisite to consider complexity. In general, it may be challenging to summarise the reliability of information in a CLD, especially as multiple types of evidence are used concurrently. We sought expert validation to partially address this limitation.

Fifth, it is not clear how or to what extent it may be possible to incorporate a social justice/social cohesion lens in a CLD.(13) Although the CLDs that we produced can be used to consider possible causes of social inequities, this requires an additional layer of analysis and is not immediately obvious.

Finally, it is challenging to convey that CLDs should not be interpreted as definitive nor as tools for prediction, but rather as transparent summaries of hypothesised causal pathways.[19181817] We emphasize that this is not a forecasting tool; CLDs suggest relationships and hypotheses to be further examined.

7 CONCLUSIONS

We used a complex systems approach to review and synthesise evidence relating to how street trees interact with the system around mental health, developing series of causal loop diagrams (CLDs) using evidence of relevance to Europe and China. We identified a number of pathways and contextually influential factors, with evidence of feedback and reinforcing loops which can have positive but also negative consequences. Our results identify a number of factors, such as competition for resources within systems, that should be taken into account when considering the implementation of street tree programmes. Whist we considered a substantial body of literature for this analysis, we suggest that there is still a need to build the evidence base and to develop a more sophisticated understanding of *how* street trees are thought to operate within the complex systems that produce health and wellbeing, using a systems-thinking approach.

While there have been many calls for a systems-informed approach to synthesising evidence and interventions in complex systems,(11,17,71) there are fewer worked examples or step-by-step methodological guidance around exactly how to operationalise these calls. In the context of having long causal chains and multiple mechanisms, traditional systematic review approaches are insufficient. We have demonstrated a process of iterating between evidence and theory generation through the development of a CLD for complexity-informed evidence synthesis. We also suggest that CLDs are a useful tool to bridge disciplinary gaps and may facilitate knowledge exchange and development around interventions in complex systems.

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